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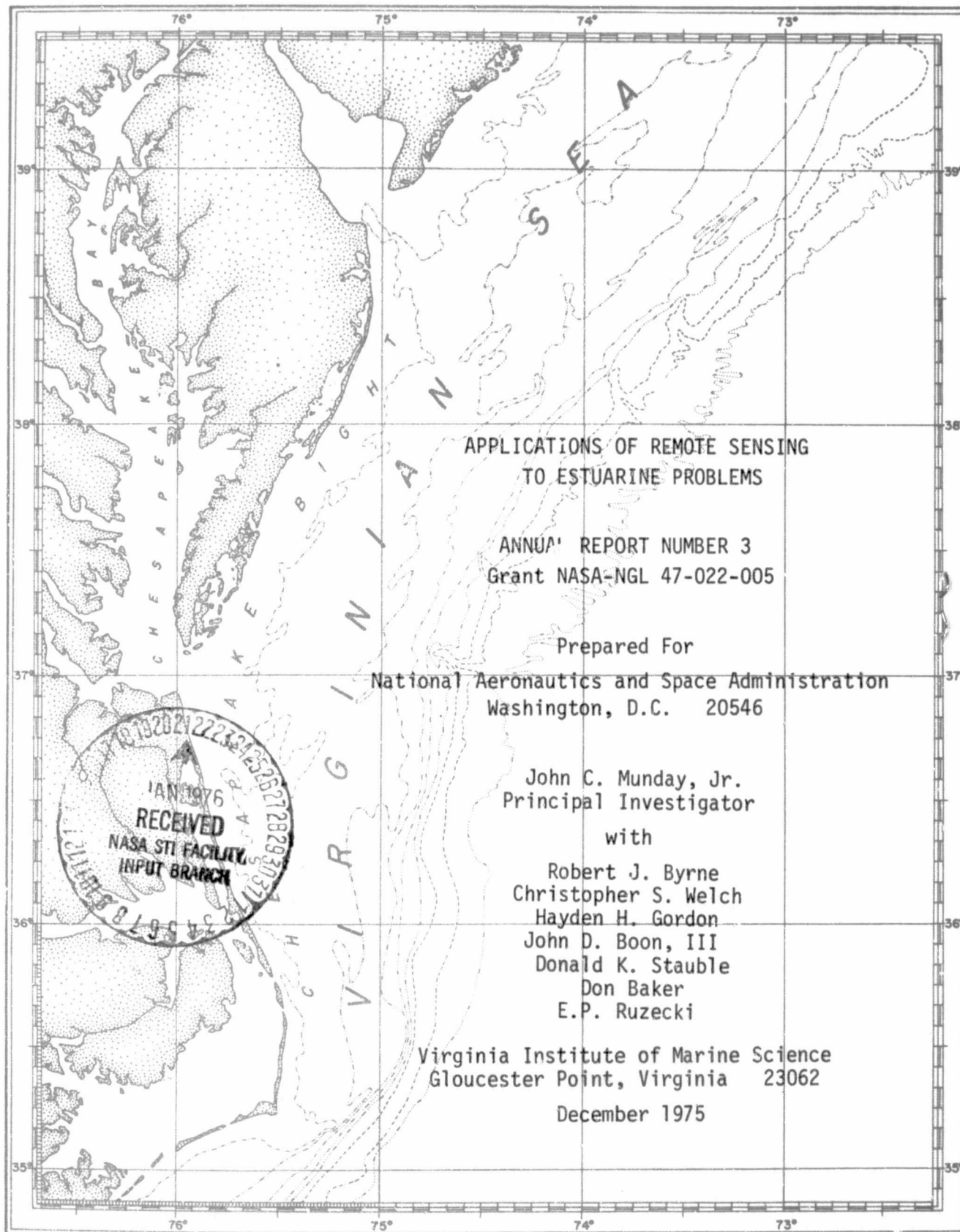APPLICATIONS OF REMOTE SENSING
TO ESTUARINE PROBLEMS

ANNUAL REPORT NUMBER 3
Grant NASA-NGL 47-022-005

Prepared For

National Aeronautics and Space Administration
Washington, D.C.   20546

John C. Munday, Jr.
Principal Investigator

with

Robert J. Byrne
Christopher S. Welch
Hayden H. Gordon
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Virginia Institute of Marine Science
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CONTENTS

ABSTRACT

A variety of siting problems for the estuaries of the
lower Chesapeake Bay have been solved with cost beneficial remote
sensing techniques. Principal techniques used were repetitive
1:30,000 color photography of dye-emitting buoys to map circulation
patterns, and investigation of water color boundaries via color
and color infrared imagery to scales of 1:120,000. Problems
solved included sewage outfall siting, shoreline preservation
and enhancement, oil pollution risk assessment, and protection
of shellfish beds from dredge operations.

SUMMARY

Remote sensing has been applied by the Virginia Institute of Marine Science to a variety of estuarine problems in the lower Chesapeake Bay during 1974-1975. The problems involved siting issues which required collection of site-specific tidal-current and circulation data.

A dye-buoy/remote sensing technique was developed for circulation study which cut costs in half compared to alternate methods. Problems were solved in weeks rather than months. The aerial imagery provided comprehensive views and allowed analyses of circulation patterns not obtainable by other methods. In particular, the significance of water color boundaries, ignored by other methods, was exploited directly to satisfy user needs.

The technique was profitable for a mixture of siting problems. Tidal currents eroding a shoreline with a promontory were successfully analyzed, and recommendations given to the City of Hampton for beach protection and enhancement. Alternate sewage outfall sites in Hampton Roads were rapidly evaluated for their potential for dispersing effluent; the Hampton Roads Sanitation District Commission has accepted the recommendation for a site further offshore than the existing outfall. Pathways of suspended sediment around an artificial marsh were tracked for the U.S. Army Corps of Engineers; the Corps used the data to select sampling locations for impact evaluation. Dredging causing sediment dispersal near shellfish beds was monitored; the dredging contractor was thereupon constrained to operate only during ebb tide, in

order to protect the beds from excessive sedimentation. Finally, oil spill beaching zones were predicted for a proposed oil refinery site.

This report begins with an introductory section which outlines research/advisory obligations of the Virginia Institute of Marine Science, and reviews methods for analyzing estuarine tidal-current fields. A second section devotes a chapter to each problem addressed during 1974-1975. The final section describes in detail the methodology employed, with emphasis on fast-response techniques, the novel construction of dye buoys, and the successful testing of a low-cost radio buoy suitable for mapping circulation on the continental shelf.

ACKNOWLEDGEMENTS

FIGURES

Figures, Cont'd.

TABLES

PART ONE: INTRODUCTION

1. THE GENERAL PROBLEM OF SITING

The most important and immediate problem facing coastal zone planning and management agencies is that of siting. Coastal zone siting issues arise repeatedly. They develop from the fact that coastal zones are rich with varied attractions--relatively mild climate, numerous recreational possibilities, shipping and harbor facilities, fishery resources, cooling waters for industries and utilities, and offshore oil and gas resources. These attractions stimulate coastal population growth which is twice as fast as that of interior regions of the United States. Industries and utilities, wishing to capitalize on the resources and serve a growing population, develop and expand their activities. This growth puts coastal water quality under increasing pressure. Figure 1 shows the rapid growth of sewage discharge into the lower James River Estuary of the Chesapeake Bay, illustrating just one of the many pressure points on coastal water quality.

Planning and management agencies are well aware that deterioration of water quality leads to loss of biological and recreational resources, and occasionally to a threat against human health. Consequently, a high priority concern, beyond monitoring and control of pollution from existing facilities, is wise site selection for new, potentially damaging activities. The specific siting issues which commonly arise in the coastal zone and estuarine environment are sewage outfalls, power plant
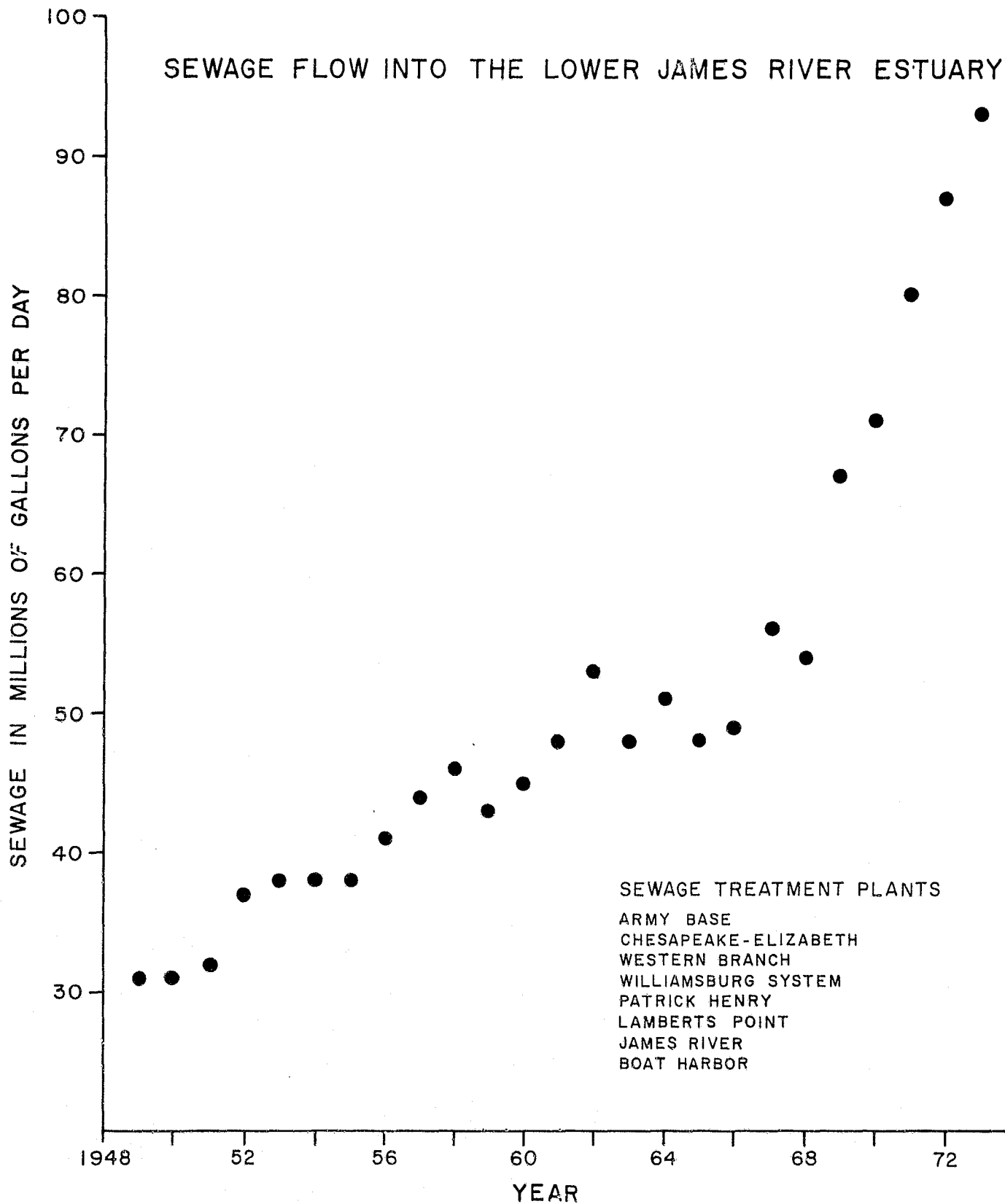
Figure 1. Sewage flow into the lower James River Estuary.

discharges, industrial effluents, dredge spoil disposal, bridge and channel placement, petroleum processing facilities, and shoreline land-use policy.

In a broad sense, the coastal zone management question is "What activities should be allowed in coastal zone waters, and where should they be located." To properly answer the where part of the question it is necessary to assess the relative merits of alternate proposed sites. A major part of the impact assessment of alternate sites is the delineation of the geographic sphere of influence of the proposed activity. Such delineation requires a detailed knowledge of the water circulation:

> The delineation of estuarine circulation is a first order priority in answering questions of coastal siting.

Ideally, a site selection for any particular activity would be based upon a pre-screening of proposed sites. This would include an evaluation of the circulation at all alternate sites. Until recently, the study of alternate sites was frequently omitted. The omission was due to lack of funds, and lack of a readily accessible data base on circulation at the various sites.

This poor state of affairs need persist no longer, because remote sensing is a cost-effective aid in alternate site evaluation. Projects reported herein show how circulation analysis accomplished rapidly via remote sensing techniques has proved pivotal in resolving siting issues. The range of issues has been broad, encompassing sewage outfall siting, shoreline preservation, and shellfish bed protection.

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2. VIMS AND COASTAL ZONE MANAGEMENT

The Virginia Institute of Marine Science (VIMS) is in a critical and unique position with respect to siting questions. As a state agency it has, by law, the responsibility to act as the principal advisor to the Governor, General Assembly, and other state agencies on all matters pertaining to the marine environment and marine resources of the Commonwealth. The Institute's responsibilities include identification of marine problems and knowledge gaps, as well as solutions to problems identified by other agencies. In particular, the Virginia State Water Control Board and the Virginia Marine Resources Commission request and act upon advice and recommendations provided by VIMS. The range of interest includes interstate affairs affecting marine resources of the Commonwealth.

Furthermore, VIMS acts as a research and educational institution. VIMS consequently has great flexibility to develop new techniques and apply them to basic and problem-oriented research.

Acting in the roles outlined above, VIMS is itself a user of its own products (such as new methods and study results). It is, as well, an interfacing agency between the scientific community engaged in remote sensing research and other users.

It is important to note that a great majority of the activity at VIMS is mission oriented and applications oriented. The Institute is daily confronting Virginia's current issues concerning waters of the Chesapeake Bay and its estuaries.

3. HISTORICAL SOLUTIONS TO THE SITING PROBLEM

Over the past few decades, the most common approach used in circulation investigations was the <u>hydrographic survey</u>, involving deployment of current meters fixed in the stream, with simultaneous measurement of the vertical profiles of temperature and salinity. The data were pieced together to provide a generalized picture of the average flow structure. However, this average-flow picture does not specify the path or sphere of influence of a point source input. Moreover, such surveys are costly, as they involve large amounts of time, equipment, and personnel.

To avoid costly repetition of field surveys, some oceanographers and engineers turned to <u>physical models</u>. The models are calibrated on the basis of hydrographic survey data. Useful results have been obtained with the James River Model at Vicksburg, Mississippi (operated by the U.S. Army Corps of Engineers), and construction of a Chesapeake Bay Model is underway in Maryland. Physical models, however, have serious drawbacks. One critical drawback for many small-area siting problems is that the reduction in scale inherent in the model blurs details of intermediate-scale (so-called mesoscale) and large scale (small area) circulation patterns. Other drawbacks include the vertical exaggeration in the model, and a question as to the validity of scaling water mass properties from areas of square kilometres to square metres. Generally, one always wonders whether the physical model is sufficiently verified.

The next stage of development was the coupling of field data with numerical solutions of the equations of motion, continuity and mass balance for the construction of mathematical models for average flow conditions. The greatest drawback to mathematical modeling is that the intrinsic three-dimensional nature of the flow is enormously difficult to model. Consequently the models generated have been one-dimensional (downstream average changes are described but variables are lumped and averaged over any given cross-section) or two-dimensional (downstream and vertical changes are described but variables are lumped and averaged laterally). These methods have been very useful and those developed by VIMS are in use by the Virginia State Water Control Board to predict, for example, average oxygen concentrations for various loadings of domestic sewage. There are two striking weaknesses in these mathematical models. The first is that the real cross-sectional topography of the stream is not used, rather an equivalent prismatic channel. Formerly, no specific information was provided for the shallower flanks of the cross-section. In recent models, flank water volumes are presumed to interact only with adjacent deep water; sequential aerial photography shows this to be a false presumption, nevertheless it is mathematically convenient. This is a very serious drawback as it blurs the detail of the area where many discharges are made. The second weakness in the approach is that it will not predict where discharges from a particular point will go--in in other words the motion-path of a particular water mass is not "traced".

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Another alternative is the dye-dilution study. The dye-dilution technique is presently the most widely-used technique in the United States for siting questions, where dispersion for a point source is to be evaluated. After a site has been selected as a discharge point, execution of a dye-dilution study is generally required to complete the design.

In a dye study, a large point release or a steady continuous release of Rhodamine dye is made. The dye concentrations are measured for several days by boat-borne fluorometers. The data allow calculation of a dispersion coefficient which measures the combined effect of advection and turbulent diffusion. From the dispersion coefficient, one can obtain effluent concentrations as a function of time and distance from the source. This technique is very useful for a small area, or for a region where the water body lacks dynamic large-cell structure with fronts and convergence zones. Since estuaries do show this structure, the dye-dilution study is at times severely compromised in its validity. Furthermore, dye-dilution studies are generally very expensive because of the large volumes of dye required.

4. THE REMOTE SENSING METHOD

In truth, no single technique from those discussed in the previous chapter will answer all circulation questions. Those conventional approaches inadequately specify the circulation on the shallower flanks of the estuaries, and the circulation associated with convergence zones and vertical motions in the main stream. As a result there has been a growing demand for empirical "tracer" studies to resolve particular siting questions. The tracer studies are performed by tracking current drogues moving with the fluid. This Lagrangian approach is preferred because it is direct evidence of the water motion.

Remote sensing is an obvious choice for tracking a set of Lagrangian current drogues. Photogrammetric analysis then yields current velocities. This has been a standard tool in circulation analysis for over two decades (see for example Keller, 1963; National Ocean Survey, 1971; Yeske et al., 1975).

Our work in the past year on the James River demonstrates a new possibility for the remote sensing/photogrammetric approach. Dye buoys were incorporated which permitted the identification and mapping of submergence zones (even though the circulation process at depth was not specified). Dye markings elucidated the link between submergence zones and strong water color boundaries, by permitting the mapping of the surface circulation flow field in the neighborhood of such a boundary. Observations of the York River indicate similar water color patterns at locations geometrically similar to those on the James River. The patterns

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appear repetitively and persist through particular phases of the tide. The evidence on hand suggests that water color boundaries in tidal estuaries, in conjunction with foam lines, represent submergence zones. The only method which is adequate in mapping the flow field in the presence of such zones is remote sensing.

Even when submergence zones are absent, a high density of data points is essential for accurate mapping of non-linear water mass boundaries and complex flow fields. Only remote sensing provides the necessary high density.

Finally, remote sensing is much faster than conventional methods. Fewer people and less equipment are required, allowing a remote sensing effort to be initiated more quickly. The data collection is centralized and uniform, allowing faster data reduction. Remote sensing is faster even with its limitation to daytime data acquisition.

The applications summarized in the next chapter and detailed in Part Two generally involved the use of dye buoys and aerial photography at various scales. Most of the photography was obtained by VIMS personnel. The rest was NASA imagery from high altitude missions.

5. SUMMARY OF APPLICATIONS

A series of siting questions was solved during the past year using remote sensing to delineate water masses and circulation patterns. Tables 1 and 2 summarize the applications. Geographically, the project sites were concentrated in the Hampton Roads area, at the junction of the lower Chesapeake Bay and the lower James River. Figure 2 shows the locations. Table 1 lists the applications and indicates alternative methods which would have been used in the absence of remote sensing methods. The ratio of the alternate-method cost to the remote sensing cost is listed, along with the advantages of remote sensing. Table 2 indicates the remote sensing methods employed, the direct and indirect users, the outcome of each project, and the origin of funding. Note that further developments are underway in 1975-1976 for some of the projects.
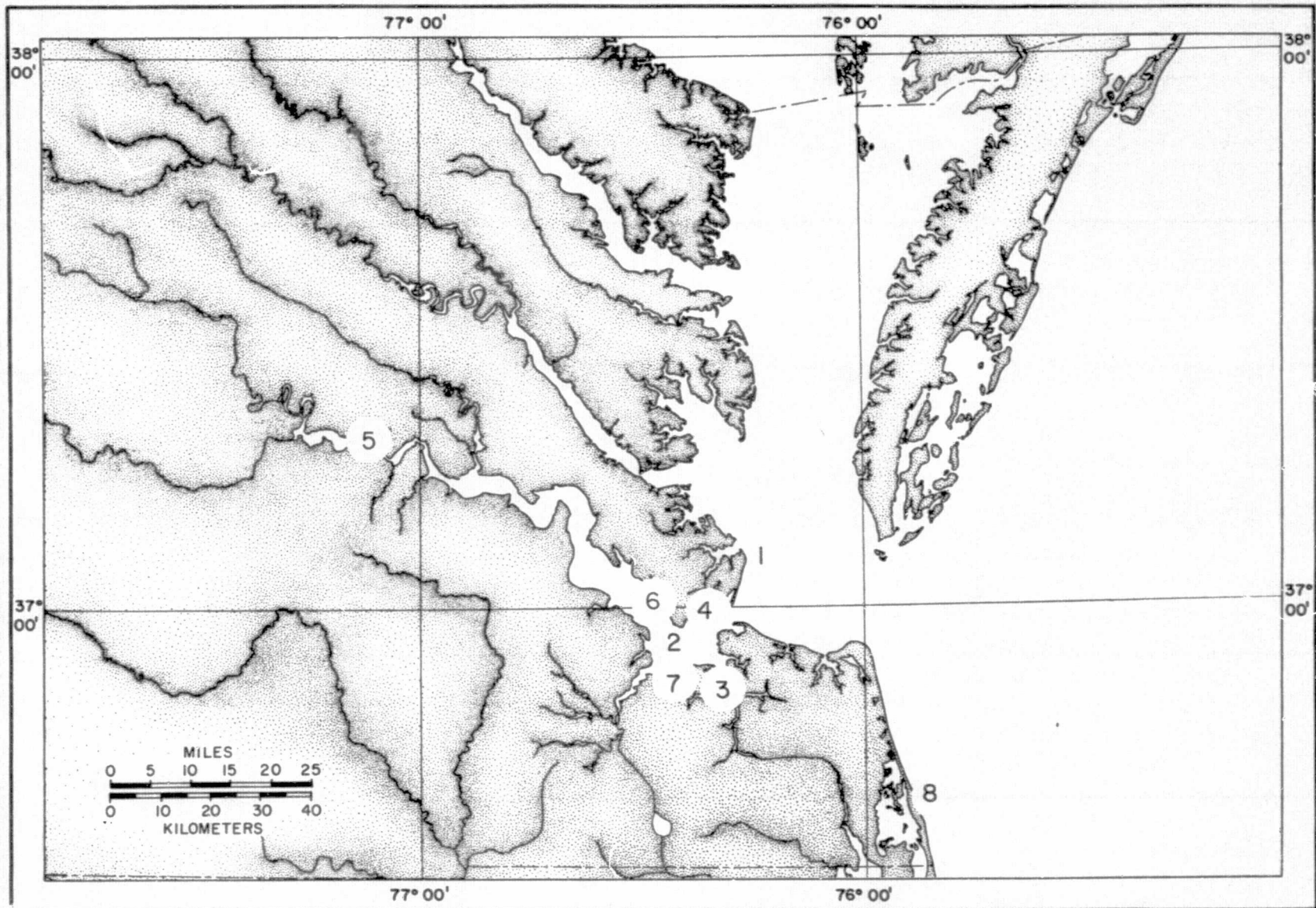
Figure 2. Sites of Remote Sensing Applications, Hampton Roads, Virginia. The numbers correspond with chapters in Part Two. 1) Grand View shoreline. 2) Newport News Point sewage outfall. 3) Portsmouth oil refinery. 4) Hampton Bar dredging. 5) Windmill Point artificial marsh. 6) Newport News shipyard water quality. 7) Pig Point sewage outfall. 8) Coastal research.

TABLE 1.   Summary of Applications for 1974-1975. Alternate Methods Comparison.

Application	Goal	Alternate Methods	Cost Ratio--Alternate/Remote Sensing	Unique Advantages of Remote Sensing
1. Grandview Nature Preserve Shoreline	Site of recreational beach. Site of structures to protect and enhance beach.	Current meter array	1.8	Comprehensive overview of circulation
2. Newport News Point Sewage Outfall	Site of sewage outfall.	Dye dilution study. Current meter array Radar buoys	5.0	Overview of complex flow field. Characterization of submergence zones. Tracing of outfall plume.
3. Portsmouth Oil Refinery	Assess oil pollution danger. Determine response of surface waters to wind.	Drift cards (marginal)	---	Convenient and rapid surface flow field mapping under variety of wind and tidal conditions.
4. Hampton Bar Dredging Monitor	Avoid siltation of shellfish beds.	Comprehensive surface sampling for suspended sediment concentrations.	---	Morphology of turbid plume.
5. Windmill Point Artificial Marsh	Locate water quality sampling sites for turbidity impact.	Comprehensive surface sampling for suspended sediment concentrations.	1.8	Morphology of turbid plume.
6. Newport News Shipyard Water Quality	Avoid adverse water quality during ship construction.	Current meter array (chemical sampling the primary methodology in either case).	1.8	Discrimination of possible pollutant sources from circulation patterns.
7. Pig Point Sewage Outfall	Site of sewage outfall	(Dye dilution study with fluorometry was the primary methodology).	---	Morphology of dye plume.
8. Coastal photography for Research	Map coastal dunes and beach profiles	Ground survey	---	High density of data points on permanent record.

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TABLE 2.   Summary of Applications for 1974-1975.   User Linkage.

Application	User Linkage	Outcome	Origin of Funding
1. Grandview Nature Preserve Shoreline	VIMS → City of Hampton	Decision by City of Hampton to build nourishment groin at location specified by VIMS. Groin incorporated into park plan.	100% NASA grant
2. Newport News Point Sweage Outfall	VIMS → Hayes, Seay, Mattern & Mattern → HRSDC, EPA	Decision by HRSDC to build sewage outfall 400-600 feet further from shore than old outfall. Public hearings in progress.	$ 6,074. Hayes, Seay, Mattern & Mattern (approved by HRSDC, charged ultimately to HRSDC).
3. Portsmouth Oil Refinery	VIMS → NUS Corp. Hampton Roads Energy Co., Va. Marine Resources Comm., City of Portsmouth, State Energy Office, EPA	Results presented to NUS. NUS report to VMRC and EPA pending.	$6,024* NUS Corp. (approved by HRSDC, charged ultimately to HRSDC).
4. Hampton Bar Dredging Monitor	VIMS → Newport News Shipbuilding & Dry Dock Co - dredging company	Decision by Newport News Shipbuilding & Dry Dock Company to have dredging firm cease dredging on flood tide. Dredging now complete.	$40,000 Newport News Shipbuilding & Dry Dock Co.
5. Windmill Point Artificial Marsh	VIMS → U.S. Army Corps of Engineers	Decision by Army Corps to collect water samples at sites recommended by VIMS. Sample collection and artificial marsh monitoring under way.	100% NASA grant
6. Newport News Shipyard Water Quality	VIMS → U.S. Dept. Navy	Acknowledgment with thanks for imagery from the U.S. Navy. Chemical sampling by VIMS under way. Further imagery planned during next water quality "event".	100% NASA grant
7. Pig Point Sewage Outfall	VIMS → McGaughy, Marshall and McMillan/Hazen and Sawyer → HRSDC	Dye study results presented to HRSDC. New site proposed by HRSDC has necessitated additional remote sensing study by VIMS in new contract year.	100% NASA grant
8. Coastal photography for research	VIMS	Research still in progress	100% NASA grant

* An asterisk by an application indicates that it involved other work and funding not related to remote sensing. Only the remote sensing component is included here.

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PART TWO: APPLICATIONS

1. GRAND VIEW NATURE PRESERVE SHORELINE

THE PROBLEM

In late spring of 1974 the City of Hampton requested that VIMS assist in the planning of the layout for a public use seaside nature preserve. The question, in particular, was whether the coastal reach under consideration could be protected from further erosion and whether the beach quality could be enhanced.

The Grand View nature preserve consists of a narrow strip of beach, bordered on the south by the community of Grand View, on the north by the Back River and on the west by an extensive salt marsh. Figure 3 shows the general location in the lower Chesapeake Bay. The existing beach, shown in Figure 3, is a thin veneer of sand overlying an eroding marsh with typical low-lying backshore sand dunes. As the waves attack the beach face, the entire morphology moves westward over the marsh, with the sand derived from the erosion deposited at a terminal spit at the entrance to Back River. Inspection of the area and study of older maps indicate very high erosion rates. Moreover, it is apparent that the supply of sand to the alongshore drift system is small; this is due to the relatively small length of coast (several miles) and to the orientation of the coast to incoming wave energy. The shoreline bends at Lighthouse Point, changing from northwest/southeast to northeast/southwest. The small sand supply is typical of many reaches of coast along the highly invaginated shoreline of Chesapeake Bay.

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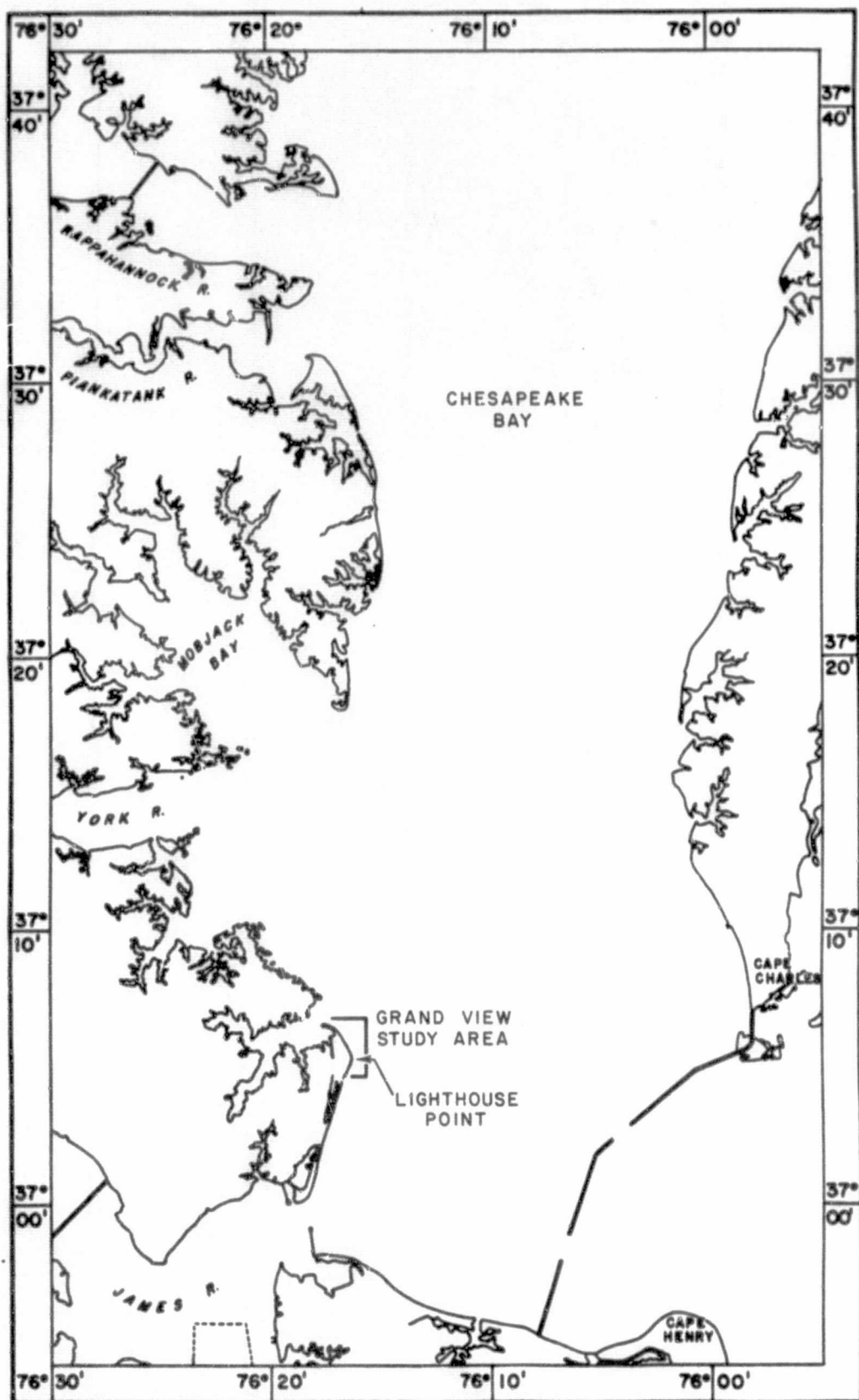
Figure 3.   Grand View, Hampton, Virginia, on the lower Chesapeake
Bay. The coastal prominence is Lighthouse Point, site
of a former lighthouse.

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Given that erosion rates are high, and the supply of sand moving along the beach is small, the application of engineering structures (i.e., groins) to trap sand generally do not function well.

The goal of our study was to determine the feasibility of installing engineering structures to inhibit erosion and/or to enhance beach quality. Enhancement is of considerable importance as the existing beach is a thin veneer of sand, pebbles and cobbles, with widespread outcroppings of the eroding marsh. From the point of view of recreational use, the beach without ehnancement can hardly be considered attractive.

Our initial analysis of the situation led to the conclusion that the effectiveness of a large groin system was likely to be poor. However, inspection of aerial photography showed that there is considerable sand offshore in the form of longshore bars and in a fairly massive shoal off Lighthouse Point. The questions then arose whether this sand could be used to artificially fill a groin system, and whether the shoal at Lighthouse Point was a result of particular wave and tidal circulation conditions which would permit exploitation to enhance the beach. Observation of the beach morphology indicated that the direction of net sand drift along the beach was northward for the area north of Lighthouse Point, and southward for the area to the south. Of course, there are times when the direction of sand drift would be uniform throughout the entire area; for example, with waves from the southeast one would expect sand to move north along the entire reach.

The central technical question concerning the tidal current in the region may be appreciated by examining Figure 4. The study site lies between Back River and the James River, a major waterway. On the flood phase of the tide, water enters both the Back and the James Rivers. Since both rivers act as sinks during flood tide there must be a nodal point or region along the coast connecting the two rivers where the tidal flow diverges. Conversely, on the ebb flow, tidal waters issue from both the Back and James River. If these flows are parallel to the beach (southward out of Back River, and northward from the James River) there must be a nodal point or region where these tidal flows converge and turn offshore. The central question was to determine if such nodal points exist in the Grand View area, and if so, how they might be used to advantage with the beach stabilization and enhancement program.

THE CHOICE OF REMOTE SENSING

Longshore drift is commonly evaluated using loose fluorescent dye dropped by hand into nearshore water. In the Grand View case, the offshore bars would have necessitated additional repeated dye drops by boat; the required periodic observations over a large area of quickly diffusing dye patches would have been completely impractical by boat.

A better method in some situations is the use of a current meter array. Here a current meter array was impossible, because of the bars and shoal, and the general shallowness of the region.

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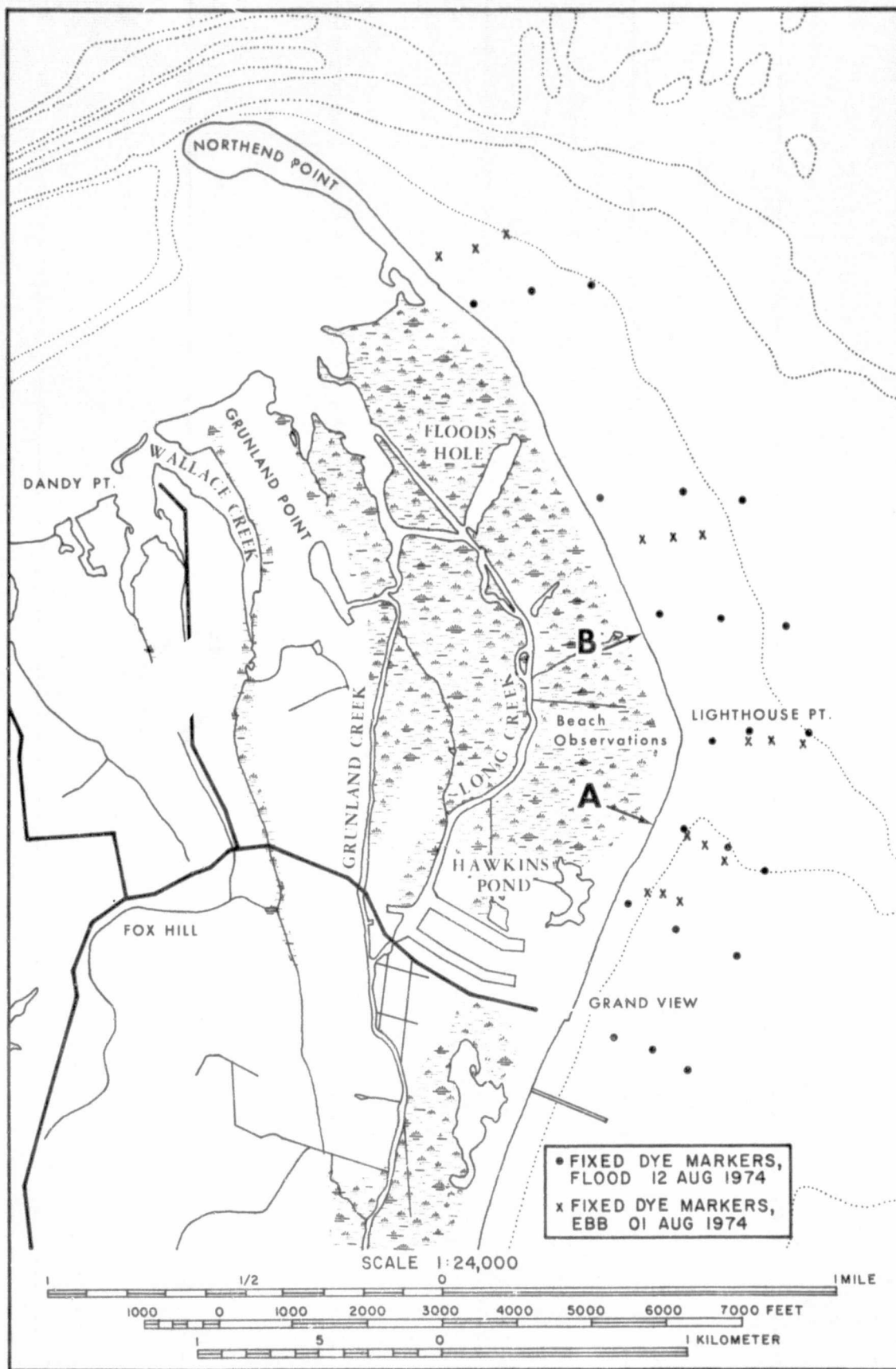
Figure 4. Grand View Beach and Marsh. Dye buoy deployment sites are marked in the nearshore waters. Points A and B were the sites of onshore beach observations.

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Previous VIMS experience in the late 1960's with dye drogues and NASA photography at the Chesapeake Bay Mouth suggested the alternative of sequential aerial photography of the dye emitting drogues and anchored buoys. This alternative was also viewed as inexpensive, and financially on par with costs envisioned by the City of Hampton for beach enrichment.

METHODS

The circulation study was therefore conducted using a coordinated program of aerial photography, dye-emitting markers, and simultaneous beach measurements. Sequential aerial photography was used to image the direction of dye streaming from anchored buoys (called "streamers"), and dye emitted by free floating surface drogues (called "floaters"). This information, when plotted to a common scale, enables the calculation of surface current velocity vectors and the current flow field.

Two studies were conducted, one for each half of a tidal cycle. The first was conducted on August 1, 1974 when the predicted tides (National Ocean Survey, 1974 Tide Tables) at Messick Point in the Back River (closest station) indicated a falling tide, which will be referred to as the ebb case. The second study took place on August 12 during a predicted rising tide, representing the flood case. (The possible presence of nodal points renders the terms "ebb" and "flood" somewhat inapplicable in the usual sense.) The times of overflights relative to the predicted

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tidal levels are shown in Figure 5. Although the times did not
encompass the entire tidal cycle, the results pointed convincingly
to the conclusions.

SURFACE PROGRAM

The water surface program was conducted from a boat with a
two man crew operating within one kilometre of the beach. The
boat crew positioned an array of fixed and free floating dye markers
containing Sodium Fluorescein cast into a solid (see Chapter 2
in Part Three for casting methods). Figure 4 shows the location
of the anchored dye markers as they were originally placed on the
two experiment days. The position of additional fixed markers
which were placed later in the ebb experiment is not shown, nor is
the location of free floating surface dye drogues.

Shoreline observations were made by a two man beach crew,
who recorded wave period, wave direction, longshore drift, and
wave height. Wave period was determined by timing the passage
of ten waves past a point. Wave direction was estimated with a
Brunton compass by measuring the angle between wave front normals
and the beach face normal. To determine longshore drift a small
amount of Sodium Fluorescein was released beyond the breaker zone
directly in front of a reference stake on the beach. Two other
stakes were placed on the beach 15 m away from the reference
stake (one on each side), and the time recorded for the dye to
travel this distance parallel to shore. This method is success-
ful only when longshore drift is sufficient to move the dye

EBB – AUGUST 1, 1974
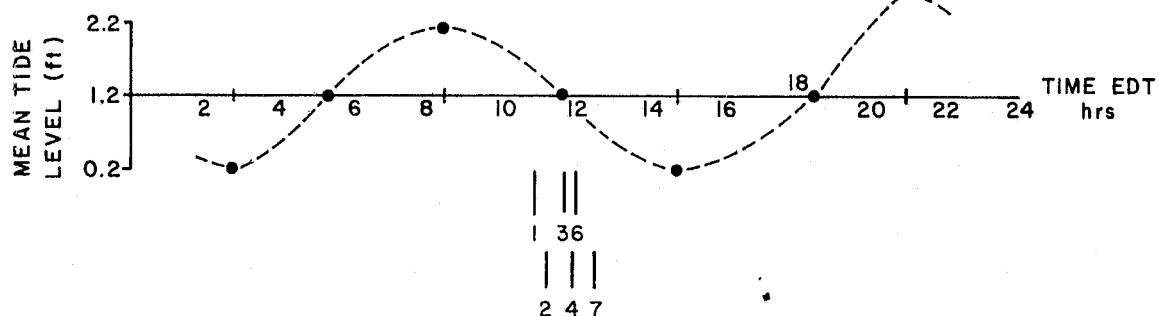
FLOOD – AUGUST 12, 1974
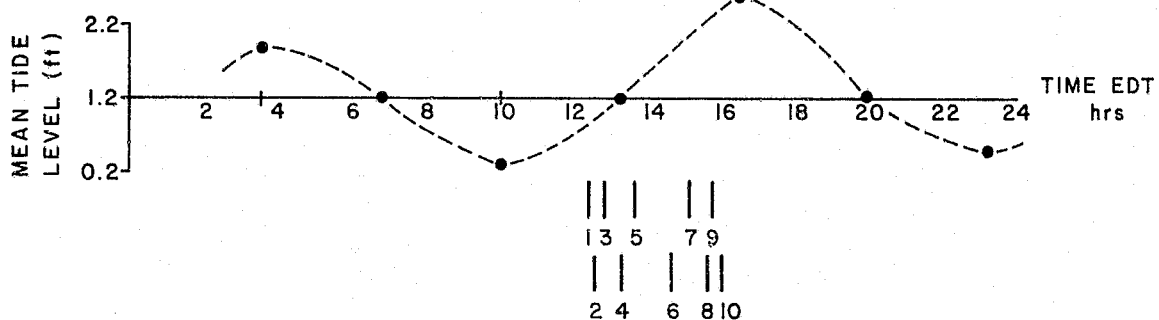
Figure 5.   Tides at Messick Point near Grand View on dates of
studies. Photographic runs are indicated as numbered
vertical bars below the tide curves.

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between the stakes before it has a chance to diffuse, and even then it is difficult to determine when the highest concentration has traveled the 15 m distance. Wave height was an average of 50 readings (difference between crest and trough), measured with a surveyors rod beyond the zone of breaking waves. Due to the physiography of the beach with two distinct straight segments, the measurements were made at two locations, one in each beach segment (A and B in Figure 4).

Two way radio communication was used between the beach, boat and aircraft crews to coordinate the various aspects of the study. Communication is extremely important to the boat crews in monitoring the buoys, placing new markers, and retrieval of equipment, all of which can be easily directed from the aircraft.

The remote sensing was accomplished from a single engine light aircraft modified with a hole in the fuselage to enable vertical aerial photography (see Chapter 1 of Part Three for details). A Hasselblad 500 EL/M camera with a 50 mm lens was used with 70 mm Kodak High Speed Ektachrome color film. A 35 mm Nikon F camera with a 55 mm lens was employed for oblique photos as required, and for determining the proper exposure for the Hasselblad camera. Sequential photographic runs were made over the area to map the dye markers. Most photographic runs were made parallel to the beach face from Grand View to Northend Point at an altitude of 1500 m. Care was taken to maintain straight and level flight and a constant altitude while photographing through the

camera port. Photographs were taken with 50% forward lap to minimize the effect of sunglint which is worst with high summer sun elevations.

RESULTS

Vertical photography from the Hasselblad was returned from processing in the form of 70 mm color positive transparencies at a nominal scale of 1:30,000. A Bausch & Lomb model ZT4 Zoom Transfer Scope was employed to adjust the photography to a scale of 1:24,000 and transfer image points of dye markers onto a series of topographic base maps. These have been arranged in time serial form and portions reproduced as Figures 6 and 7 for the ebb and flood experiments. Anchored dye markers are depicted by a circle with a tail (source of dye is within the circle, the direction of current is along the line away from the circle). Free floating surface drogues are indicated by a circle-enclosed cross, numbered to permit identification throughout the flight sequence. Current speed determined from the time serial positions of the floaters is given in Table 3. Velocity is in all cases parallel to the immediate shoreline. The speed listed is the average over a relatively long period of time, with an uncertainty of ± 0.01 m/sec. Shorter time periods would have led to larger uncertainty. The correspondence between the times of the photographic runs and tidal stage may be obtained by reference to Figure 5. Examples of imagery are shown in Figure 8.
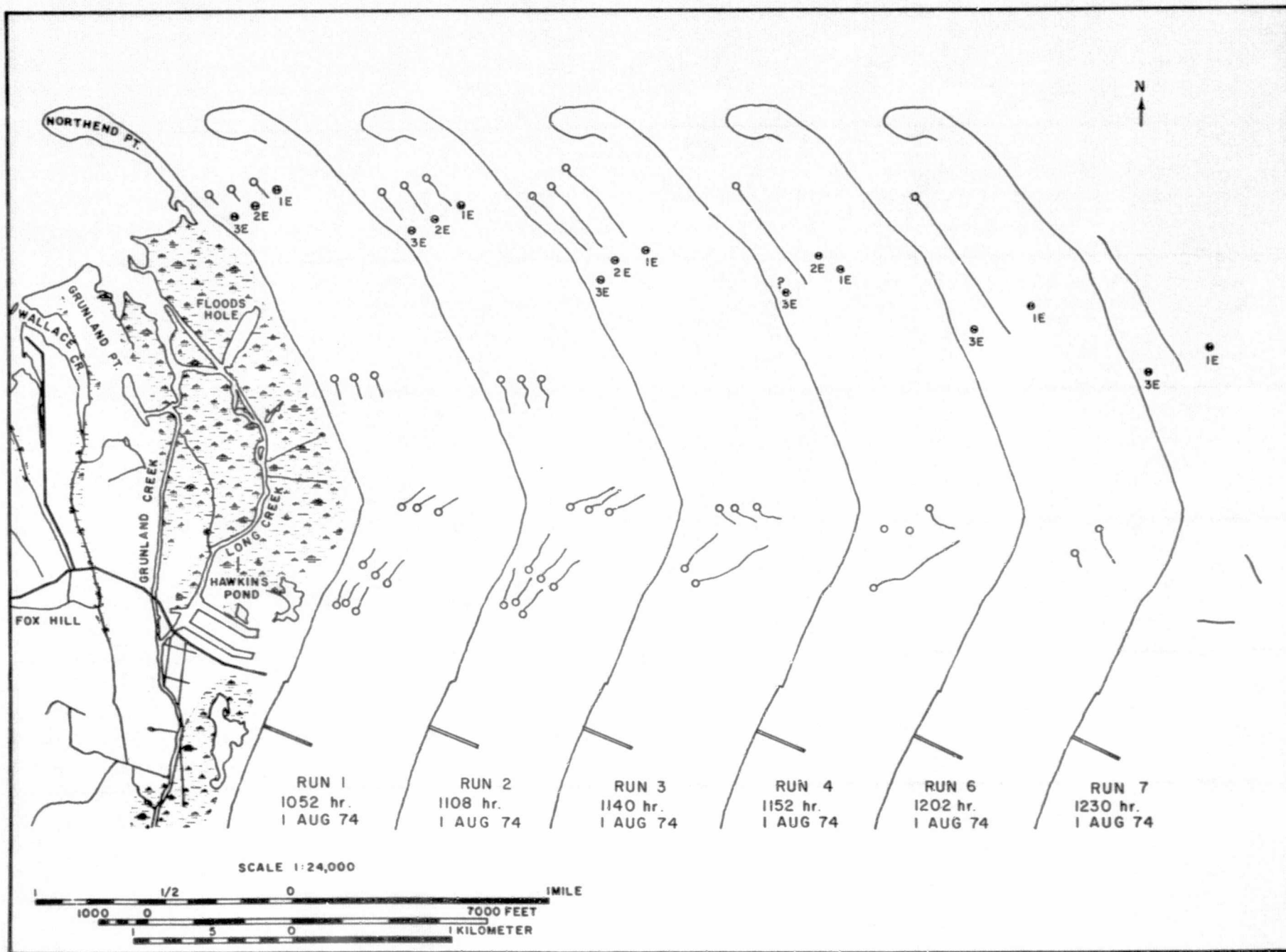
Figure 6. Dye tracks, Grand View, ebb tide. The nodal point progresses southward past Lighthouse Point.
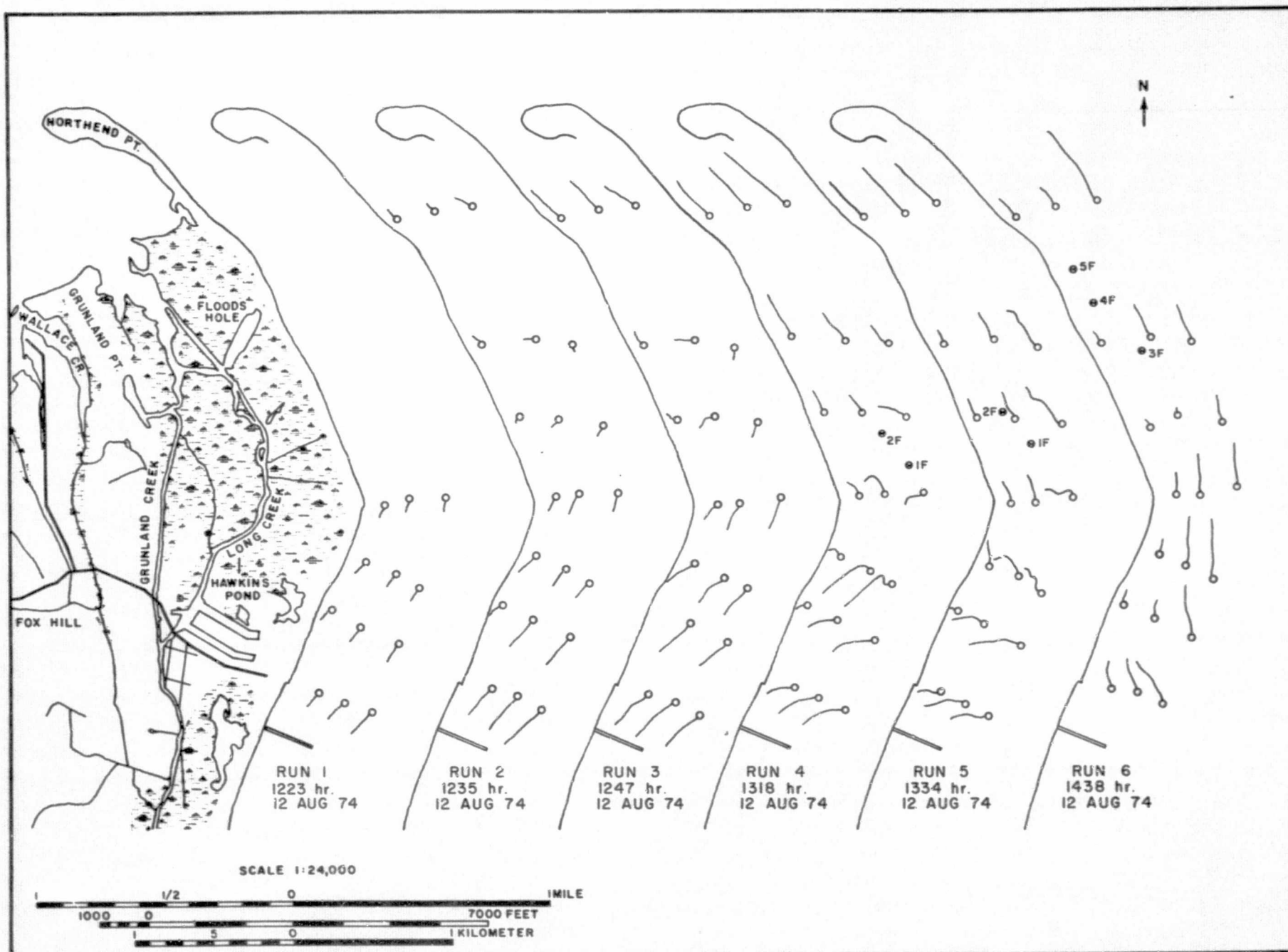
Figure 7a. Dye tracks, Grand View, flood tide. The nodal point progresses south-
ward past Lighthouse Point (similarly for the ebb tide).
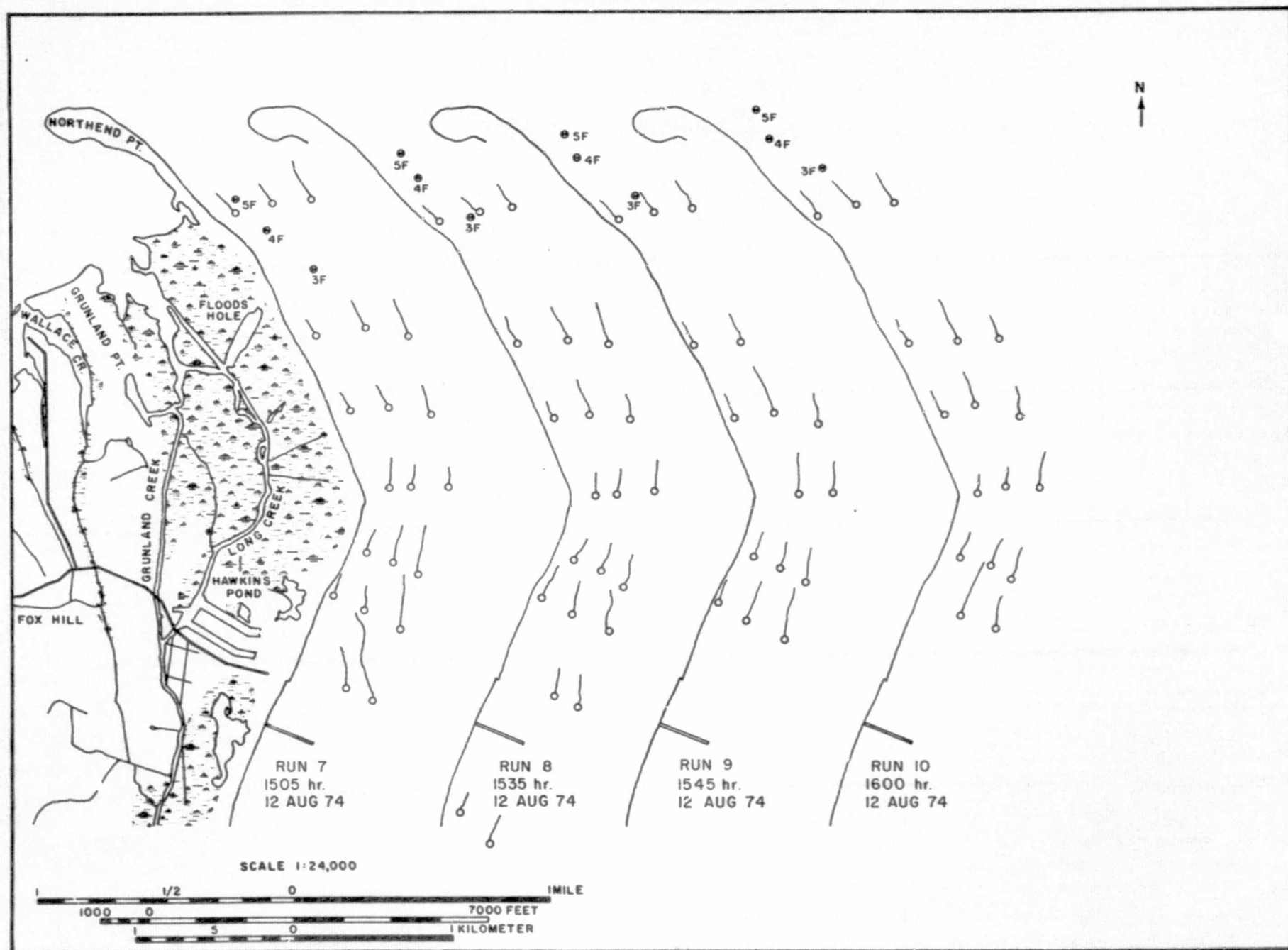
Figure 7b. Dye tracks, Grand View, flood tide, continued.

TABLE 3. ABSOLUTE CURRENT VELOCITY, GRAND VIEW STUDY

Floater #	Time (EDT)	X_1^*	Y_1	X_2	Y_2	ΔT (sec)	V (m/sec)	V (knots)	Dist (m)
1-E	1052	---	---	950	500	---	---	---	---
	1108	950	500	1060	620	960	0.17	.33	163m
	1140	1060	620	1350	840	1920	.19	.37	364m
2-E	1052	---	---	1060	380	---	---	---	---
	1108	1060	380	1160	460	960	.13	.26	128
	1140	1160	460	1400	640	1920	.16	.30	300
3-E	1052	---	---	1140	240	---	---	---	---
	1108	1140	240	1240	320	960	.13	.26	128
	1140	1240	320	1540	540	1920	.19	.38	372
1-F	1318	---	---	240	510	---	---	---	---
	1334	240	510	440	700	960	.29	.56	276
2-F	1318	---	---	460	680	---	---	---	---
	1334	460	680	640	880	960	.28	.54	269
3-F	1438	---	---	1000	1000	---	---	---	---
	1505	1000	1000	1460	1300	1620	.34	.66	549
	1535	1460	1300	1870	1570	1800	.27	.53	491
	1545	1870	1570	2000	1660	600	.26	.51	158
	1600	2000	1660	2140	1800	900	.23	.43	198
4-F	1438	---	---	1300	1300	---	---	---	---
	1505	1300	1300	1720	1580	1620	.31	.61	505
	1535	1720	1580	2120	1940	1800	.30	.58	538
	1545	2120	1940	2220	2040	600	.24	.46	141
	1600	2220	2040	2350	2100	900	.16	.31	143
5-F	1438	---	---	1500	1450	---	---	---	---
	1505	1500	1450	1940	1780	1620	.34	.66	550
	1535	1940	1780	2260	2020	1800	.22	.43	400
	1545	2260	2020	2370	2110	600	.24	.46	142
	1600	2370	2110	2530	2180	900	.19	.38	175

* X, Y positions in m _relative_ to UTM grid.

Figure 8. Imagery from the Grand View study.
Top: Flood tide. Bottom: Ebb tide.
Color prints from slide copies of the
original 70 mm transparencies.
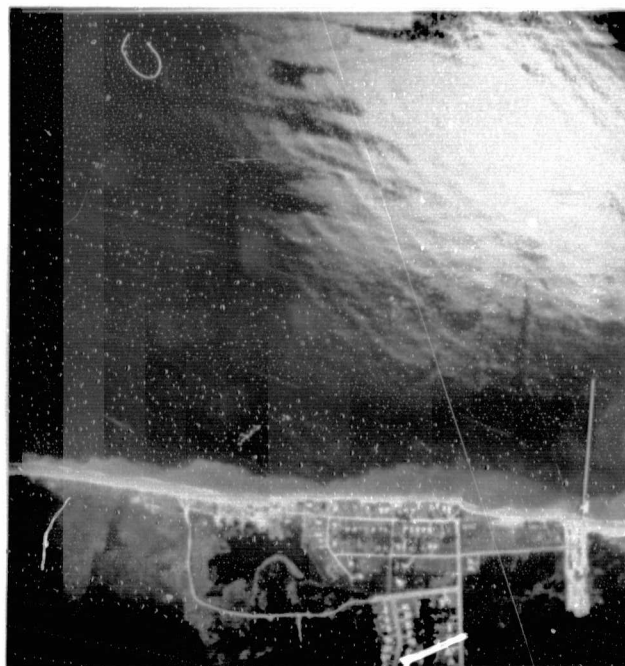
The pivotal feature of the results is the location versus time of a nodal point (a convergence zone on flood and a divergence zone on ebb).

The nearshore circulation for the ebb case (Figure 6) is characterized by a nodal point in the vicinity of Lighthouse Point which progresses southward with time. The flow is parallel to the shore both north and south of Lighthouse Point; consequently water is forced directly offshore into deeper water from the convergence point. During the later portion of the ebb photography there appears a water color boundary marking the convergence zone. Dye flowing to the zone was trapped by the color boundary. Beach measurements indicated small waves and very slight longshore drift.

During the flood phase (Figure 7a, 7b), a nodal point is again formed near Lighthouse Point. During the first part of the flood phase, water flowing shoreward from the Bay diverges north of Lighthouse Point. Nearshore flow is parallel to the shore away from the divergence area. Later in flood the nodal divergence zone progresses southward and passes to the south of Lighthouse Point as high water is approached. Beach measurements after passage of the divergence zone indicated longshore drift to the north.

Thus, progression of the nodal point past Lighthouse Point was observed in both half-tidal cycles; consequently, on either or flood, flow can be found at some time directed either north or south on both sides of Lighthouse Point. Nevertheless, the northerly directed currents have a dominance along the shoreline south

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of Lighthouse Point, because the tidal cycle is skewed to allow greater time to the flood portion. Furthermore, on ebb, the flow from Back River will be concentrated as a jet straight into the Bay by the bathymetric profile at the mouth.

Two important facts emerge from the study of the nearshore tidal flow. First, the circulation patterns offer an immediate explanation for the presence of the shoals immediately offshore of Lighthouse Point. The divergence of the tidal currents in this area results in reduced sediment transport capacity with the consequence of shoal formation. Second, to the south of Lighthouse Point, the tidal currents were predominantly northward. It is reasonable to surmise, therefore, that the principal source of the sand in the shoals has been the eroding shoreline to the south of Lighthouse Point.

SOLUTION AND ACTION

The purpose in executing the study of the tidal circulation was to examine whether that circulation might be utilized in enhancement of the beach. The results of the study indicate the most favorable location for application of a coastal structure would be at Lighthouse Point in the lee of the nodal zone. Accordingly, VIMS made the following recommendation to the City of Hampton during a VIMS presentation to city officials:

> Construct a groin between the backshore of the beach and the remains of the old lighthouse at Lighthouse Point (groin length about 400 feet). This

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structure will prevent wave driven sediment trans-
port across the nodal zone. Accretion of sand
beach is expected to occur primarily on the south
side of the groin.

As accretion proceeds anchor the trapped sand
by construction of a breakwater parallel to the
beach and connected to the seaward end of the groin.

The City of Hampton has accepted these recommendations in
the planning of the nature preserve.

SAVINGS, BENEFITS, AND COSTS

There are two points in the evaluation which deserve emphasis.
These are: (1) the unique character of the information obtained,
and (2) the cost savings.

The character of the information is unique in that the
imagery itself supplies an instantaneous plan view of the flow
field. Even without further analysis for current vector inform-
ation, this qualitative view could in many cases provide the inform-
ation necessary for solution. In addition, the transport patterns
of suspended sediments may immediately be correlated with and ex-
plained by the circulation patterns. Remote sensing has provided
a view not otherwise attainable.

A conservative cost comparison illustrates the cost saving
using the remote sensing application to determine flow field as
compared to the conventional approach using in situ current meters.
Table 4 shows approximate costs incurred in the Grand View study.
Table 5 shows costs for the same study if it were accomplished

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with current meters. In both tables (and in all similar tables in later chapters), an indirect cost factor of 100% of direct costs is included to account for start-up and ongoing methods, development costs, supplemental purchases, administrative expenses, and repair and maintenance expenses. As the same indirect cost factor is used in each table, any adjustments to its magnitude (for example, long-term use of any method tends to permit greater efficiency and therefore a lower factor) would have no effect on the cost ratio which compares the costs of different methods.

From the tabulated data, the current meter method would have been \$17,320/\$9,700 or 1.8 times as expensive as the remote sensing/dye-buoy method. The spatial progression of the nodal point, which was disclosed by the remote sensing, and which figures prominently in the VIMS recommendation, would have been entirely missed by any other surface-based method of practical scope. Consequently no cost ratios have been prepared for any other method.

TABLE 4. REMOTE SENSING STUDY COST DATA, GRAND VIEW NATURE
PRESERVE SHORELINE

Personnel

    Field and air
        10 man days @ $80/day $800

    Data reduction
        10 man days @ $60/day   600

    Report to User
        10 man days @ $80/day   800

Vehicle

    Aircraft/pilot
        20 hrs @ $30/hr   600

    Boat
        2 days @ $75/day   150

Materials

    Dye
        80 cakes @ $20/cake   1,600

    Buoys (rental and construction)
        44 buoys @ $5/buoy   220

    Film and processing   80
                                                $ 4,850

Indirect Costs

    Methods development and overhead
    100% of direct costs   4,850

                               TOTAL $ 9,700

TABLE 5.   REPRESENTATIVE CURRENT METER STUDY COSTS PER SITE

Personnel

    Install current meters (minimum 20)

      16 man days @ $60/day $ 960

    Film reading

      10 man days @ $60/day   600

    Plotting currents

      10 man days @ $60/day   600

    Report to User

      10 man days @ $80/day   800

Vehicle

    Boat

      8 days @ $75/day   600

Materials

    Current meter film & processing   100

    Buoy systems for current meters (rental*)   1,000

    Current meter (rental*)

      5 days @ $40/day, 20 meters   4,000

                                                $ 8,660

Indirect Costs

    Methods development and overhead

      100% of direct costs   8,660

                              TOTAL $ 17,320

*
New current meters cost $2,000.
Buoy systems cost $400.

2. NEWPORT NEWS POINT SEWAGE OUTFALL

THE PROBLEM

The Hampton Roads Sanitation District Commission (HRSDC) is in the process of upgrading and tripling the capacity of its sewage treatment plant located near the Small Boat Harbor at the end of Newport News Point. To handle the increase in effluent from the enlarged plant, a new sewage outfall will be built. HRSDC hired the consulting engineering firm of Hayes, Seay, Mattern and Mattern (Roanoke, Virginia) to design the new outfall. This firm asked VIMS to conduct a circulation study to determine the best choice among several sites for the new outfall.

The general area for the study is depicted in Figure 2. Figure 9 shows the site in detail. Newport News Point is the inside corner of a bend in the James River. Downriver of Newport News Point, the river is broad and shallow, with a dredged ship channel notched through the deep water near the mouth of Hampton Roads. Upriver of Newport News Point, the natural channel deepens and passes near the Newport News side of the river. This region is subject to a substantial tidal flow, with speeds of two knots commonly exceeded at maximum current strength. It is also a major artery for shipping traffic, from ocean-going cargo vessels to towboats and barges.

THE CHOICE OF REMOTE SENSING

The normal procedure for sewage outfall siting is to perform a dye dispersion study involving a dye batch release and
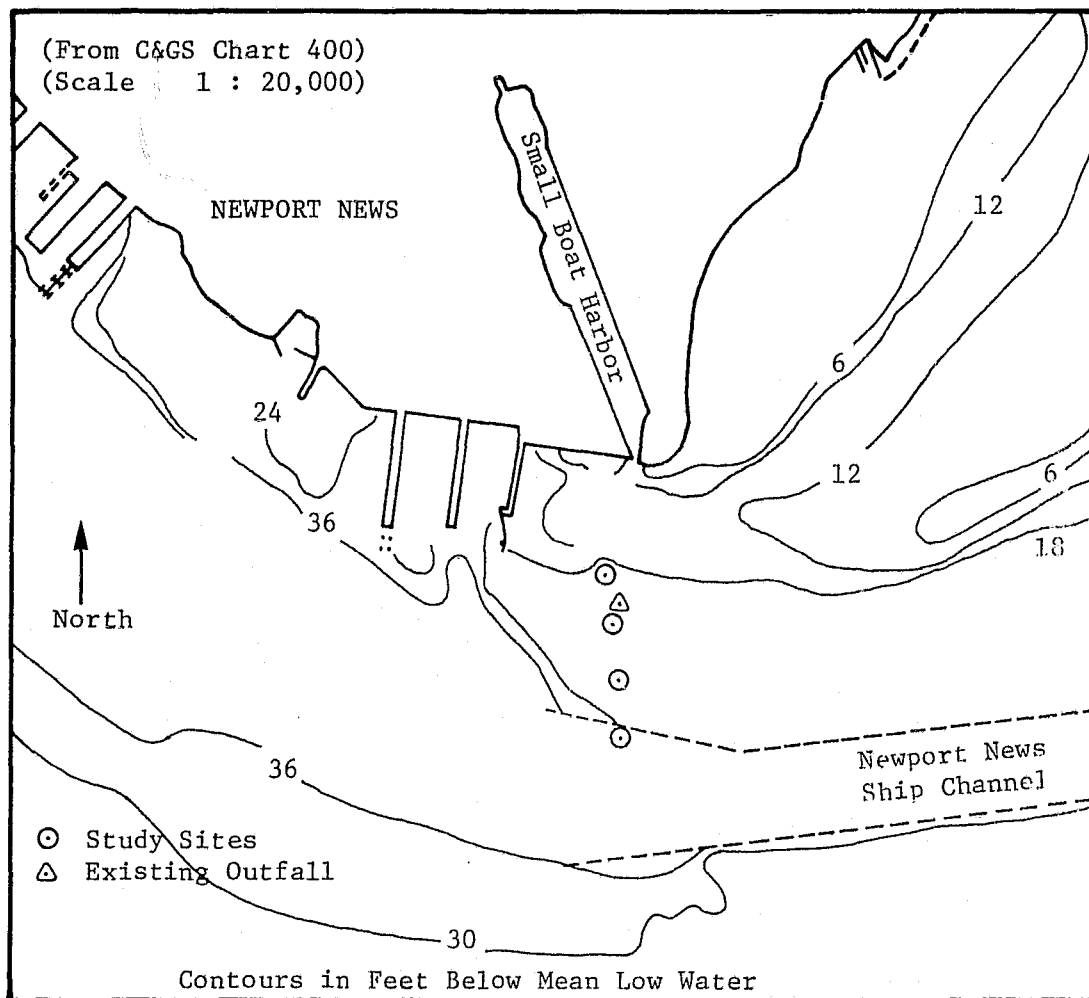
Figure 9. Newport News Point, Hampton Roads, Virginia. The buoy deployment sites for sewage outfall evaluation are shown in relation to the present Boat Harbor sewage outfall location.

fluorometers, with bottle samples or a continuous boat sampling system, at each of the separate outfall sites under consideration. The data yield the amount of dilution as a function of outfall site and reveal plume patterns when they are morphologically simple. In general, a dye dispersion study is appropriate for an outfall study, because the dye concentration can be used as a substitute in a model for the concentration of substances expected to come from the outfall (Kuo and Jacobson, 1975). Regions of high dispersion give the best chance that a critical concentration for a given parameter will not be exceeded at moderate distances from the outfall. Then the focus of interest becomes the region near the proposed outfall where concentrations may still be high.

The dye dispersion procedure was considered unjustified in the present instance for several reasons. First, a bridge-tunnel for the I-664 highway is expected to be built out from Newport News Point in the near future (this crossing was studied in a project under this NASA grant; see the annual report, Welch and Haas, 1972). When the bridge-tunnel is built near Newport News Point, in whatever form, it will probably alter the flow sufficiently that the dispersion coefficients obtained using a standard dye study will no longer be applicable to the mixing regime.

Second, for Newport News Point, a dye dispersion study would have been much more expensive than the remote sensing study. Newport News Point is a region of high dispersion because of the

large maximum values of the tidal current. This feature makes such a location favorable for sewage outfalls, since dispersal of both nutrients and biochemical-oxygen-demand occurs over a large-enough area fast enough that anaerobic conditions do not occur at any single place. This high dispersion tends to make dye or other tracer studies relatively expensive, requiring much more dye than low dispersion areas to maintain a given dye density. Dye costs are several thousands of dollars.

Third, the use of current meter strings for evaluating circulation was inappropriate for the region. The current meter technique differs from that of dye tracer studies and drogued buoy studies in that it is wholly Eulerian, measuring currents at fixed places as a function of time. Current meter data thus are appropriate for developing input and verification data for mathematical models, because methematical models are explicitly Eulerian as currently formulated. But the models are valid only over larger regions and exhibit poor spatial resolution. Furthermore, in traffic zones, current meter techniques are vulnerable to ship traffic or to intentional thievery and vandalism. This vulnerability is a frequent subject of informal discussion among practitioners of current meter techniques. It prohibits the use of current meters in the ship channel downriver from Newport News Point, for example, a place where the highest currents in the river transect occur. The correlation of shipping traffic with deep channels where highest velocities are likely to occur introduces a bias against current meter studies for sewage effluent outfall siting.

The dye emitting drogued buoys used in the remote sensing study are also subject to destruction by ships, but there are three reasons why such loss is not as crippling to the remote sensing study as to a current meter study. First, strings of current meters are more vulnerable due to their complexity. Second, the replacement cost of a dye marker is about one hundredth that of a current meter. Third, the loss can be witnessed from the aircraft as it occurs, and a replacement marker can be rapidly deployed, reducing the discontinuity in the data to an acceptable level. Damage to a current meter is not usually witnessed and may not be detected until a week or more after the data have been taken due to processing time. The resulting discontinuity in the data can be tolerated usually only if redundant information is available from nearby, undamaged meters.

Thus, the remote sensing method was chosen over alternative methods for reasons of cost, future highway construction, and experimental hazards.

METHODS

Dye-emitting buoys were imaged on color film from a light aircraft. The buoys emit dye for about six hours and can be reliably detected in images obtained at an altitude of 1500 m. The streamers were anchored at each of the four proposed outfall sites for the duration of a half tidal cycle. The floaters were deployed at regular intervals in time near the sites of the streamers, and were tracked by photography far beyond the points where dye from the streamers became invisible due to dispersion.

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Data from the resulting photographs were transferred to charts using a Bausch & Lomb ZT-4 Zoom Transfer Scope at NASA Langley. In addition to the use of VIMS photography, various rolls of NASA photographic imagery were visually inspected. The NASA imagery consisted of color and color infrared imagery from the high altitude RB-57 missions 187 and 207 over the Central Atlantic Regional Ecological Test Site (CARETS).

Two studies, one for each half of the semi-diurnal tidal flow, were performed at the proposed outfall sites.

RESULTS

Analysis of VIMS and NASA imagery shows that the local current is strongly characterized on both flood and ebb. In both cases, the current past Newport News Point flows in a well-defined direction which is locally constant for most of the half tidal cycle. Choosing deployment sites in a line normal to this direction allowed us to construct a grid diagram for each set of surface floaters which represents the history of the water past the deployment sites.

The initial mixing of effluent from an outfall occurs at the interface between the effluent and the underlying water by the process of entrainment. The rate at which a given volume of effluent mixes with the underlying water is proportional to the area of the interface. This area will increase with velocity of the water past the source and with the horizontal divergence of

the flow. Not only can velocity and divergence be evaluated easily from the constructed grid diagram, but also the increase in area. Area, the most important variable, can be evaluated directly.

The first of the two studies, on the ebb half of the tidal cycle, was conducted on August 15, 1974. Photographs were taken at regular intervals throughout the day, and the photographs were made into mosaics on which the positions of the visible buoys and dye streamers were marked. Position of the dye buoys and the direction and extent of the streamers were analyzed and trans- formed into Lagrangian trajectories starting at the outfall points in question and streaming downstream with the ebb current.

Figure 10 shows representative grid diagrams constructed from remote sensing data on ebb. These diagrams appeared in the VIMS report which was transmitted to the user (Neilson, 1975). The data indicate that the most shoreward possible location has the highest initial dispersion during early ebb, but that later the dispersion is greatest at the furthest offshore location. During later ebb, with lower currents, the dispersion is smaller everywhere than in early ebb. It was the greater amount of dis- persion at the outer site, at the time of generally least disper- sion, that led VIMS to recommend the outer site for the outfall. The analysis of the flow on the ebb tide was based primarily on the floaters.

The experiment to determine flood tide flow patterns was conducted on September 9, 1974. In the flood tide case, the
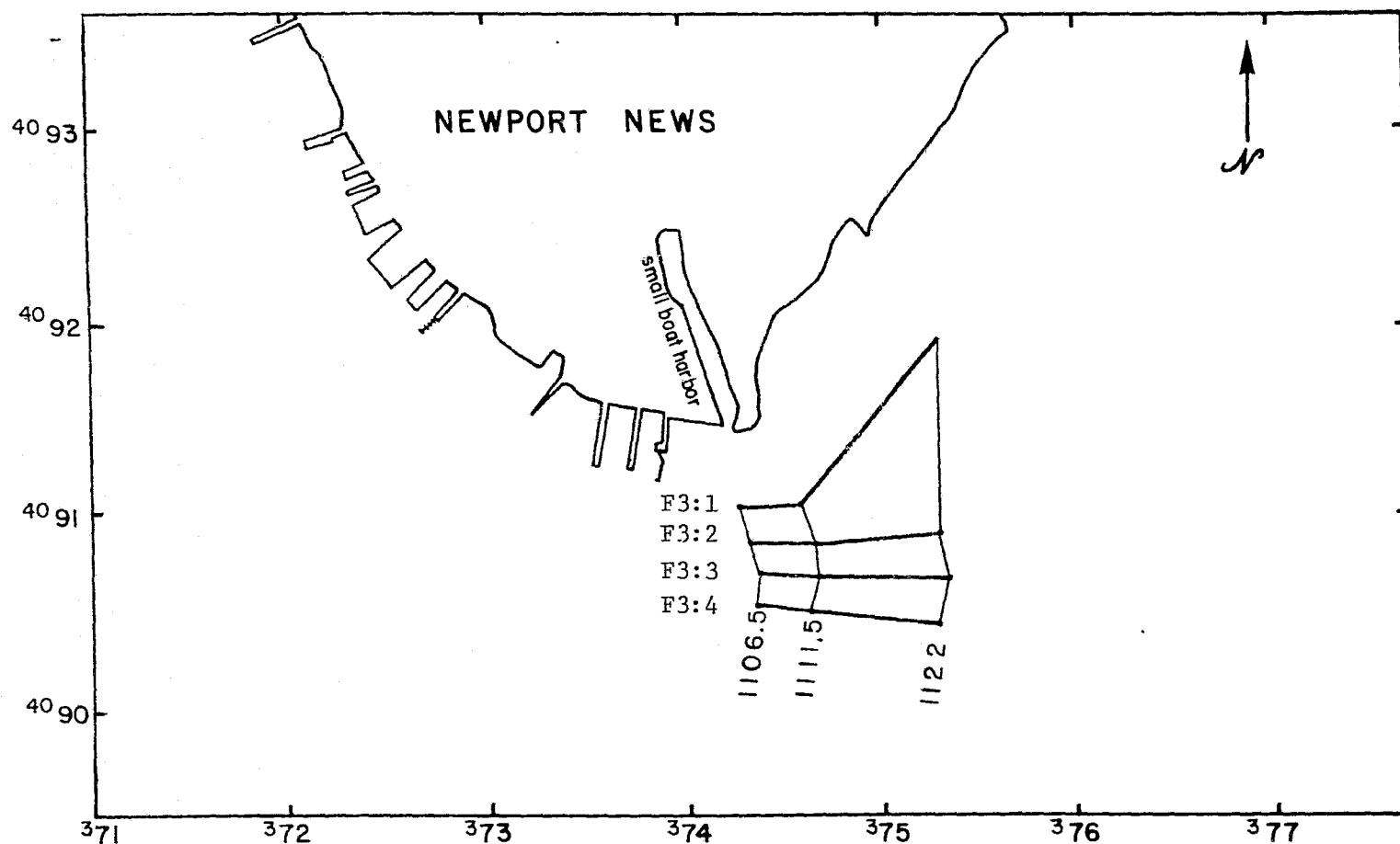
Figure 10. Ebb tide divergence at Newport News Point. Pathlines of floaters from set F 3 of the ebb experiment. Floaters were set 2 hours 33 minutes after predicted slack water and tracked for 18 minutes. The study boat followed F 3:3 until 1300, at which time it was located on the far side of the ship channel about halfway to Norfolk. Path F 3:1 shows greatest tendency of all ebb paths to travel over Hampton Flats.

streamers played the crucial role rather than the floaters. Because of the character of the flow, it was not possible to construct grid diagrams from the floater data similar to those used in the analysis of the ebb tide. The surface flow on the flood tide was not dispersive; rather, it was strongly convergent, with a concentrated zone of convergence associated with a visible color boundary in the imagery. This convergence zone dominated the flow pattern during flood tide because all of the incoming surface water passing the study site passed through this zone and submerged.

The first evidence for this singular region was that the floating dye markers behaved unusually, passing rapidly into a small region from which they exited in disarray. A similar behavior had been noted but not understood during the I-664 experiment (annual report, Zeigler et al., 1973), when radar-tracked buoys floated through the same region. The disordering of the arrays in this experiment precluded the association between a given dye streak in the image and a buoy identification, a necessary step in the construction of the grids used for the analysis of the ebb phase data. After passing the color boundary the floaters entered a fairly small area with little motion or transport, where they remained during the rest of the flood phase. The second key to understanding the dynamics of this region was that streamer plumes flowed to the color boundary and disappeared. This disappearance was direct evidence for submergence of the

water mass at the boundary. The color boundary remained stable for over four hours. An interpretation of the flow pattern is presented in Figure 11a. Figure 11b shows flood tide imagery.

In order to have remained in the small, stagnant area after passing across the color boundary, the floaters must have been separated from the flow in which they were deployed. This separation process is one which has not been appreciated before in a tidal estuary, although it is a common feature in some reservoirs (Neilson, 1975). It has implications for tidal estuaries far beyond the purpose for which this project was undertaken.

Within the scope of the present study, however, the separation of material from the flow with which it was originally associated provided an explanation for puzzling oil slicks of no apparent origin observed in the ebb tide images.

Color boundaries are a common feature of image data in tidal estuaries. If they are associated with sites of separation of floating materials from their flow, then

(1) Desirable or commercially valuable floating materials produced over the whole area of the estuary can be harvested when they gather in these restricted areas.

(2) Undesirable or polluting floating materials becoming associated with flows over much of the area of the estuary can be most easily cleaned up in these temporarily stable zones.

(3) Small areas of the estuary can be identified as particularly sensitive to the presence of floating materials.

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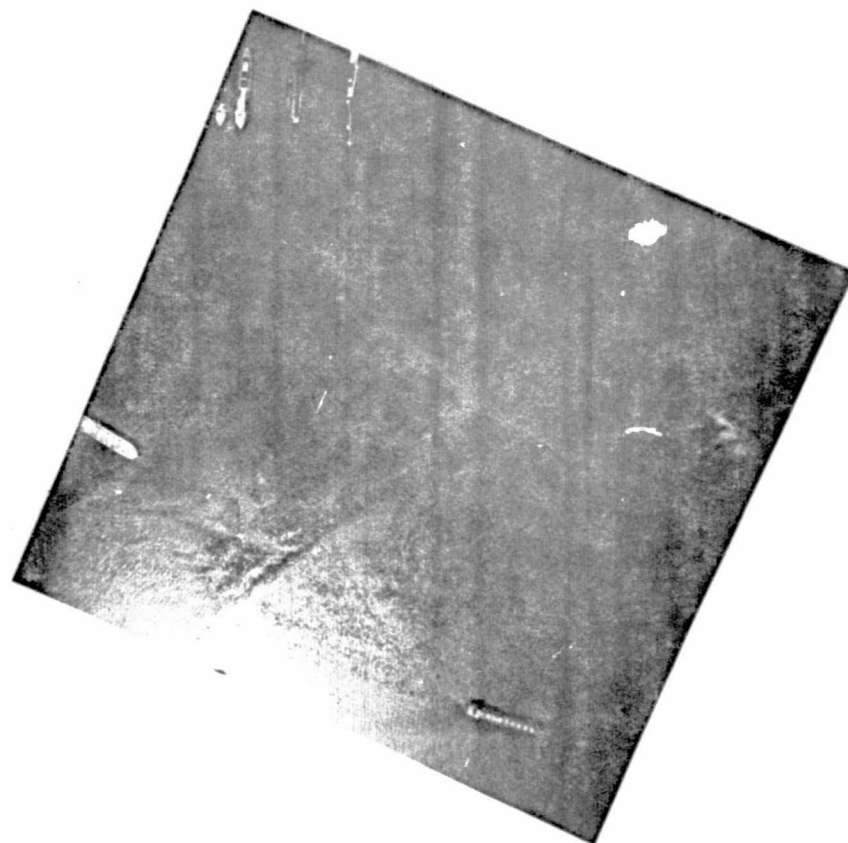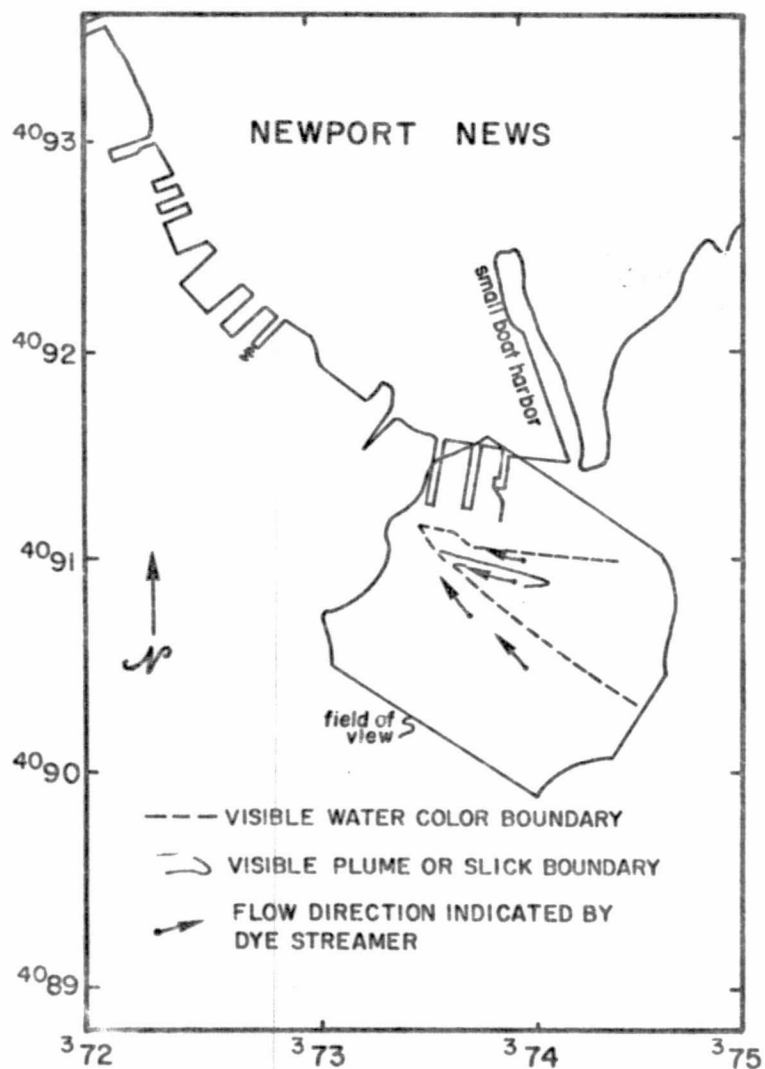
Figure 11a and b.   Flood tide convergence zone at Newport News Point.
a. Delineation of currents in region by dye buoys.
b. Imagery. Panchromatic copy of a color print from
the original 70 mm transparency.

In the present instance, the observed color boundary disappeared at the turn of the tide. The floaters which had been gathered into a small area during flood tide began to enter the ebb flow and spread out again across much of Hampton Roads. In effect, the stagnant area which has been formed during the flood tide acted as a source of floating material on the following ebb. We have termed such areas secondary sources.

If the secondary sources are produced during alternate phases of the tide in tidal estuaries, two possibilities exist for misinterpretation of the data:

1) The secondary source can be interpreted as a true source. This could be important in detection and identification of sources of pollution. In particular, a pollutant from a wide-spread source could be attributed to an apparent point source.

2) The behavior of an organism or process which produces floating material could, on the basis of the time variations of the concentration field, be erroneously linked to the tidal phase when, in fact, the flow itself was responsible for the variability given a constant source.

In the present case, any floating material which was in the vicinity of the floaters could be expected to enter the newly ebbing tide in the same manner as did the floaters. As the convergence zone is typical of flood tide, an apparent source of floating material will be found near Newport News Point. In the ebb phase imagery, a number of oil slicks were observed downriver of Newport News Point (Figure 12). These had apparently
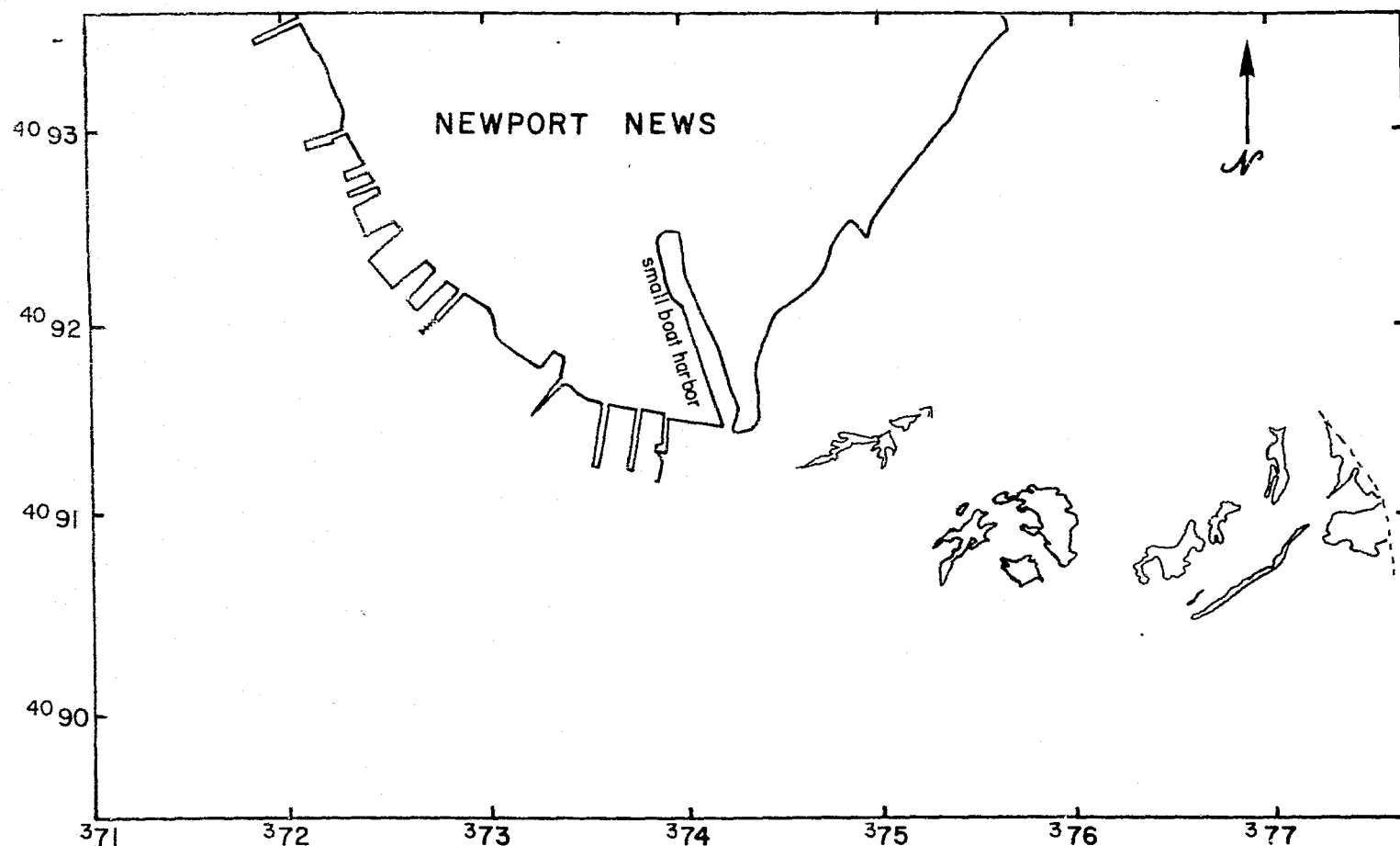
Figure 12. Oil slicks near Newport News Point. Positions of slicks observed 1 hour 58 minutes after the start of predicted ebb tide during the ebb experiment. It is highly plausible that the source of these slicks is the stagnation zone just west of Newport News Point which was formed during the middle and late parts of the previous flood tide.

derived from near Newport News Point but were not traceable back to a "point" source. Our interpretation is that these slicks came from the gathering of material which occurred throughout the preceding flood phase.

An important point to note is that the unexpected behavior of the circulation was outside the experimental design. If a more limited and directed experimental method had been employed, the surface submergence could well have escaped notice. It was the extra, unplanned data which is characteristic of images that permitted the correct interpretation of this primary characteristic of the flow field.

In addition to the direct design, the data will be used in the preparation of the Environmental Impact Statement needed to satisfy the requirements of the National Environmental Policy Act. In this context, it is our opinion that the techniques of remote sensing are not only more cost effective than the alternative methods applied to this problem, but that they promote more effective environmental safeguards due to the comprehensive coverage that is the characteristic of image data.

Applications are being investigated by VIMS for the surprising additional results about the nature of recurring color boundaries. Oil is frequently spilled in port areas from a myriad of small sources as part of current day-to-day operations. The "carpet sweeper" action associated with color boundaries may provide the key to a cost-effective strategy for reclaiming such oil.

SOLUTION AND ACTION

A full VIMS report was delivered to the firm of Hayes, Seay, Mattern and Mattern in March, 1975 (Neilson, 1975). Conclusions and recommendations are summarized in that report on pages 1-3. The firm in April, 1975 delivered to HRSDC a two volume report which describes the Boat Harbor Water Pollution Control Plant Facilities Plan. The VIMS conclusions regarding dispersion from the alternative outfall sites were incorporated into specific engineering recommendations, and these are found on pages 1-3 and 1-7 of Volume 1. Volume 2 includes the entire VIMS report. In July, 1975, HRSDC held public hearings on the proposed new treatment plant and outfall.

The substance of the VIMS findings is that "an outfall site somewhat further from shore would be better than the existing site" (Neilson, 1975, p. 3). The site closest to shore allows ebb water to flow over Hampton Flats, unsuitable for dispersion because it is a shallow region possibly subject to gyres. "The (ebb) flow past sites #2 and #3 tends to follow the edge of the navigation channel along Newport News Bar" (p. 1). The flow past the outer site turns slightly toward the middle of Hampton Roads, and thus will always avoid the nearshore shallows. "No qualitative differences in the four study sites for flood conditions could be determined" (p. 2) because of the submergence zone upstream of Newport News Point. This zone would tend to promote mixing for all except buoyant materials which become trapped at the boundary.

Hayes, Seay, Mattern and Mattern consequently recommended to HRSDC that "a new outfall be constructed...to extend to a discharge point 600' (ft) south of the existing discharge" (Hayes, Seay, Mattern and Mattern, 1975, p. 1-7; see also p. 4-10 to 4-13). This point is between sites 2 and 3 studied by VIMS.

As required by law, a public hearing on the expansion of facilities was held in July, 1975, prior to final acceptance of engineering designs. The VIMS study was acknowledged as having "pinpointed the preferred locations of the discharge..." (HRSDC Public Hearing, 1975).

SAVINGS, BENEFITS, AND COSTS

The cost of choosing the site using remote sensing was $9380 (see Table 6). A conventional dye dilution study for any one site would have cost $18,100 (see Table 7). Study of only one site would have been clearly insufficient, and at least two and perhaps all four sites would have had to be studied to answer the question adequately. The cost of four dye studies would, however, have been prohibitive for HRSDC. Based on past experience, HRSDC might have spent $50,000 on dye studies had remote sensing not been available. Thus, the cost ratio relative to a conventional dye study technique is probably $50,000/$9,380 or roughly 5:1. Note that for $50,000 HRSDC would have obtained dispersion coefficients (not obtained in this instance from remote sensing) which might be useful. However, an understanding of the convergence zones would have been completely missed.

TABLE 6. REMOTE SENSING STUDY COST DATA, NEWPORT NEWS POINT

Personnel

    Field and Air
       10 man days @ $80.day $ 800

    Data Reduction
       10 man days @ $60/day   600

    Report to User
       10 man days @ $80/day   800

Vehicle

    Aircraft/pilot
       20 hours @ $32/hour   640

    Boat
       2 days @ $75/day   150

Materials
    Dye
       64 cakes @ $20/cake   1,280

    Buoys (rental and construction)
       64 buoys @ $5/buoy   320

    Film and Processing   100
                                              ——————
                                      $ 4,690

Indirect Costs

    Methods development and overhead
       100% of direct costs   4,690
                                            ——————
                       TOTAL $ 9,380

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TABLE 7.   REPRESENTATIVE DYE STUDY COSTS PER SITE

Personnel

    Field
        10 man/days @ $80/day $ 800

    Recorder Chart Calibration
        10 man/days @ $60/day   600

    Plotting and Contouring Dye Concentrations
        10 man days @ $60/day   600

    Report to User
        10 man/days @ $80/day   800

Vehicle

    Boat
        5 days @ $200/day   1,000

Materials

    Dye
        5 barrels @ $1,000/barrel   5,000

    Fluorometer system (rental*)
        5 days @ $50/day   250
                                                             ————
                                                     $ 9,050

Indirect Costs

    Methods Development and Overhead
        100% of direct costs   9,050
                                                            ————

                                TOTAL $ 18,100

* Fluorometer system includes fluorometer, generator, pump,
   and recorder; total cost $4,000.

A current meter study would have cost $17,320 (see Table 5 in chapter 6). This is not the conventional technique for outfall siting, but it usually is cheaper than a dye study. Here, the cost would be high because the high dispersion at Newport News Point would require a larger than usual number of current meters for adequate mapping of the flow field. Remote sensing is cheaper, by a cost ratio of $17,320/$9,380 or roughly 1.7:1.

Hayes, Seay, Mattern and Mattern (with approval of HRSDC) contributed $6,074 to the cost of the study. This NASA grant contributed the rest.

3. PORTSMOUTH OIL REFINERY

THE PROBLEM

The Hampton Roads Energy Company has been formed recently for the purpose of constructing and operating a major oil refinery in the Hampton Roads area. The refinery would produce low sulfur residual fuel oil, jet fuel, liquid propane gas, and gasoline. Part of this refinery will include a marine terminal at an estimated cost of $8,000,000. The company has employed the NUS Corporation of Pittsburgh, Pennsylvania to determine the best refinery site and to design the terminal. One of the sites under consideration by NUS is in the city of Portsmouth, Virginia, on the Elizabeth River. This river is the most heavily industrialized tributary of the Hampton Roads area of the lower James River. The study site is shown on Figure 13. As the site selection process includes an evaluation of the terminal's impact on other activities in the Elizabeth River, the NUS Corporation requested VIMS to investigate the surface circulation in the vicinity of the proposed marine terminal. The primary objective of the investigation was to determine the expected routes and destinations of oil which might be spilled at the facility, under the full range of expected wind and tide conditions. NUS asked for a report in six weeks.

Previous work by VIMS in the Elizabeth River, including a study undertaken in the vicinity as part of this grant in 1972 (Welch and Haas, 1972), has indicated that the surface circulation
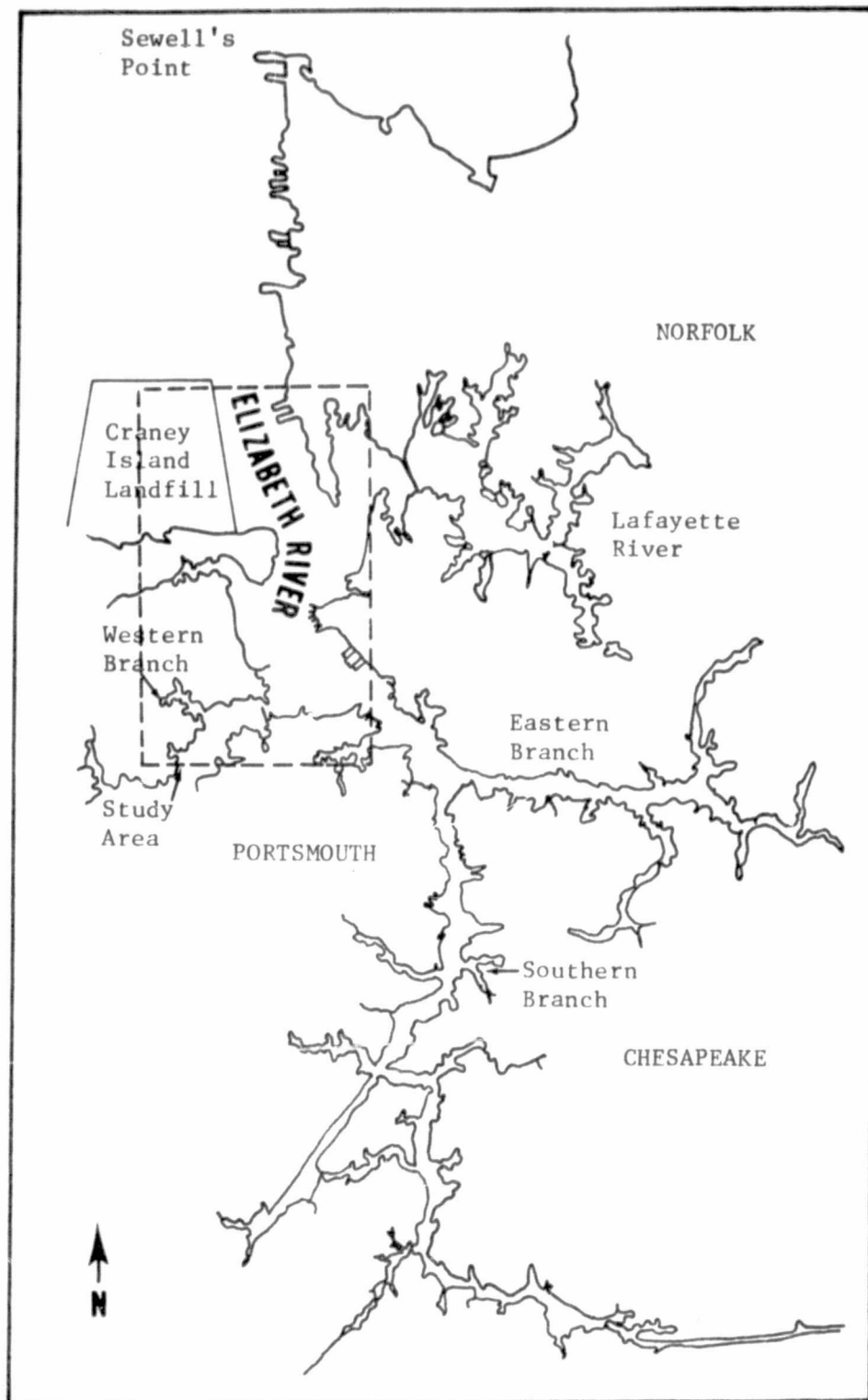
Figure 13. Portsmouth oil refinery study site on the Elizabeth River. The proposed refinery would be located below the promontory south of the Craney Island landfill.

in the Elizabeth is sluggish and highly variable depending largely on wind conditions. This indication has been reinforced by the appearance of stable high-contrast water color boundaries on NASA high altitude color-infrared imagery (Mission 187-1971; Mission 207, 1972) and SKYLAB imagery.

THE CHOICE OF REMOTE SENSING

The effectiveness of the remote sensing method having been demonstrated in the Newport News Study, it was readily chosen over other possible methods for several reasons:

1) The basin is heavily used by shipping traffic, rendering the use of fixed platforms or moored current meter strings virtually impossible. The remote sensing method did not require the use of fixed platforms or current meters.

2) Only six weeks were allowed between the receipt of the contract and the production of the draft report. Four of these weeks were left open to the field work in order to encounter as wide a range of environmental conditions as possible. The remote sensing method produced results quickly since its data reduction is not as time-consuming as that of other methods.

3) The weather dependence of each experiment required a reaction time of only ten hours in order to operate during the predicted extreme events in the month allowed. The remote sensing method was activated for each experiment within a few hours.

4) The small size of the basin made it easily compatible with the remote sensing technique.

5) The short times between buoy launch and beaching allowed sixteen separate experiments to be conducted during the four days of operation.

METHODS

The field work was conducted on February 7, 11, 20 and 21, 1975. On these days the winds in the study area were from the northwest, southwest, and northeast, and variable, with speeds from calm to 15 knots. Higher wind speeds and southeast winds, which would have made the study more comprehensive, did not occur during this period of the year. They occur later in the year. This lack did not significantly compromise the results of the study, as the fundamental responses of the Elizabeth River were excited by the available range of conditions. The results which were obtained indicate that the Elizabeth River is quite responsive to wind in a non-isotropic manner, as is suggested by the constricted nature of the basin. The conclusion is that an oil spill from the piers of the proposed refinery may travel and beach almost anywhere in the basin within about ten miles of the site. The trajectory of a particular spill, for the purpose of deploying recovery equipment, will be largely governed by the wind on the particular day in question.

The field work during each day consisted of the deployment of a single streamer to act as a "weather vane" in the local

current, and four deployments of six floaters each at predetermined locations and at two-hour intervals. The floaters were each given an identification label for recognition from the vessel after deployment. This feature proved to be quite valuable in data recovery and analysis. The floaters contained enough dye to last for an estimated six hours during the first two deployments and half that amount during the second two deployments. The resulting pattern of floaters and the single streamer was photographed throughout the day.

The photographs were taken in runs with 50% forward lap at about hourly intervals, with the interval arranged at the discretion of the photographer to follow the buoys efficiently. Between runs, the aircraft photographer directed the vessel to various visible floaters (it is impossible to find them without aircraft spotting, unless they have an undesirable amount of wind-dragging freeboard). The vessel crew identified them by the labels on their floats. The photographer then sketched the pattern onto a field chart with identifications. This technique, using free time available between photographic runs, resulted in longer intervals between photographic runs without loss of the correspondence between the dye image and the buoy identification. The decrease in number of images resulted in a significant saving of image analysis effort, currently the most time-consuming part of a given study. About 350 photographs were taken and a subset was analyzed. Figure 14 shows an example of the imagery.
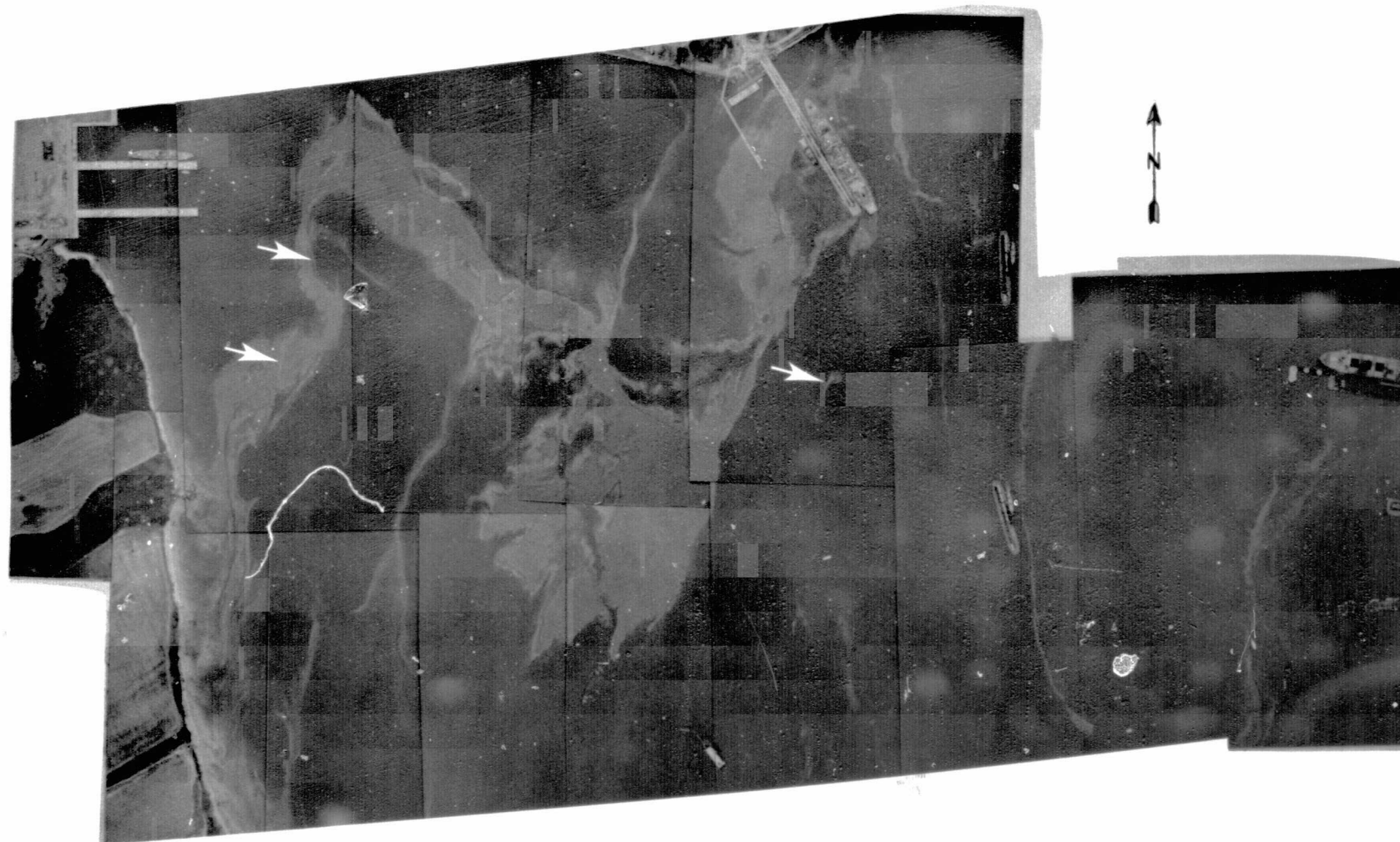
Figure 14. Elizabeth River oil slick imagery. A mosaic of color print copies of 70 mm original transparencies. Reproduced as a high-contrast panchromatic print. Dye buoys engaged the oil slick of opportunity and traveled with it as it beached. Arrows point to dye plumes.

The primary effort of the image analysis was to construct a vector record of buoy motions for each of the 100 floating markers deployed during the study (25 per day and 4 days). A Bausch & Lomb Zoom Transfer Scope at NASA Langley was used to prepare the vector maps. As found in the Newport News Point study, foam lines and water color patterns contained in the images provided a helpful context which aided in the data interpretation. Oil slicks were also imaged in the photographs, and these provided direct evidence of possible oil slick motions. As an aside, it is noted that the images yielded information of interest as examples of fluid phenomena, some of which may lead to an expansion of remote sensing techniques to other uses.

As the developers of the marine terminal were interested both in the flow near the proposed terminal, and in the eventual fate of spilled materials which might originate near the terminal, the results were presented as near and far field results. The near field results were presented as a collection of initial velocity vector patterns with origins at the six deployment sites. This collection, while presented chronologically, was also organized by the concurrent wind direction and tidal phase, obtained from nearby NOAA observation stations. The device used to organize data according to wind and tide was called a condition array, a two-dimensional array arranged by tidal phase and wind direction. The position in the array for each experiment was indicated beneath each initial velocity diagram. An example is shown in

Figure 15. The environmental conditions for all the experiments were displayed on a single condition array in order to put the study in the perspective desired by the user.

The far field results, yielding the possible extent and destination of an oil spill, were interpreted and applied in other formats. The first was an estimate of where oil would go aground based on where the observed dye markers went aground. Because we expected these data to be used in a new assessment of hazard rather than for action in case of a particular spill, the vulnerable areas were identified for all cases with no regard to particular wind or tidal conditions. These are presented as Figure 16, taken directly from the report to the user (Fang, et al., 1975).

The report to the user contains itemized conclusions and recommendations (Fang et al., 1975, Summary and Conclusions, p. 1-4). These in condensed form are: 1) the Elizabeth River has low freshwater inflow and modest tid~~ circulation; 2) surface circulation is strongly dependent on the particular combination of wind, tide, and inflow; 3) designated shoreline is highly vulnerable to oil slick beaching; 4) dye floaters behaved like oil slicks; and 5) oil spill cleanup should take advantage of naturally-occurring convergence zones.

Discussion here will be limited to features of interest for remote sensing procedures. A full discussion is found in the report to NUS (Fang et al., 1975).
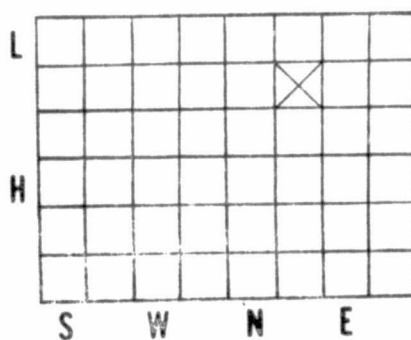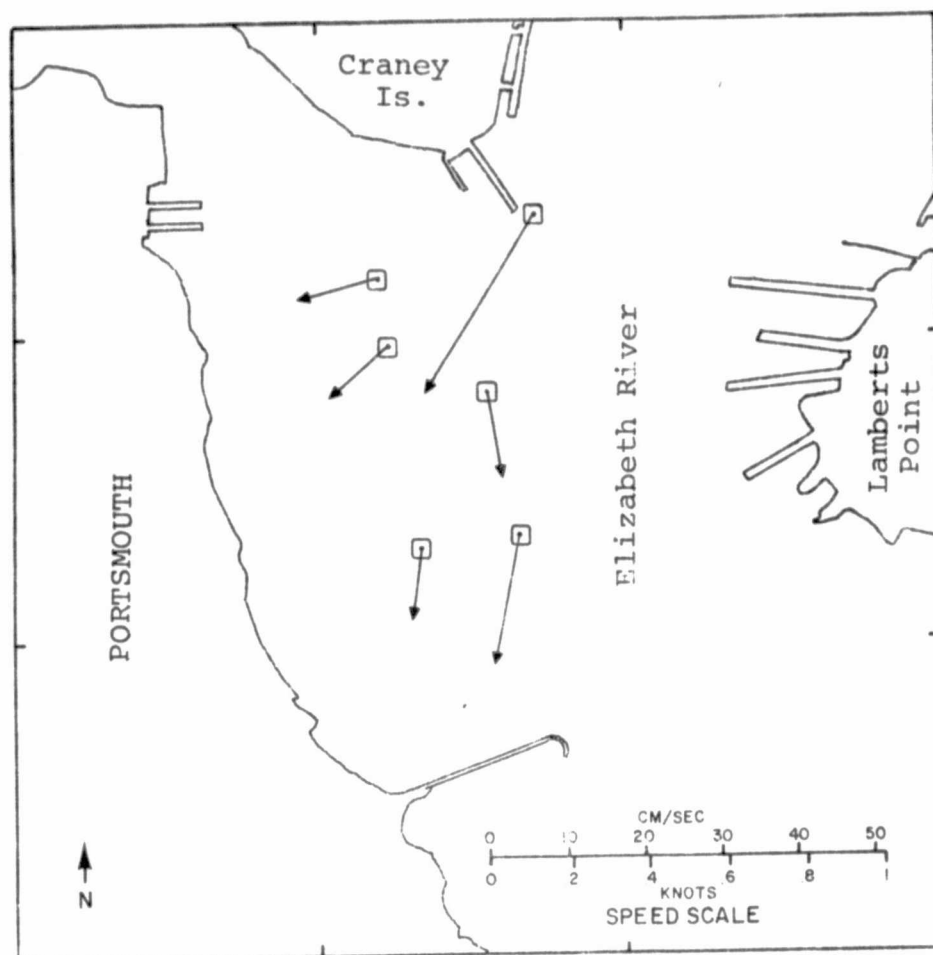
Figure 15. Elizabeth River velocity vector pattern with con-
dition array. An example of results between 1102
and 1115 EST on February 20, 1975.

64
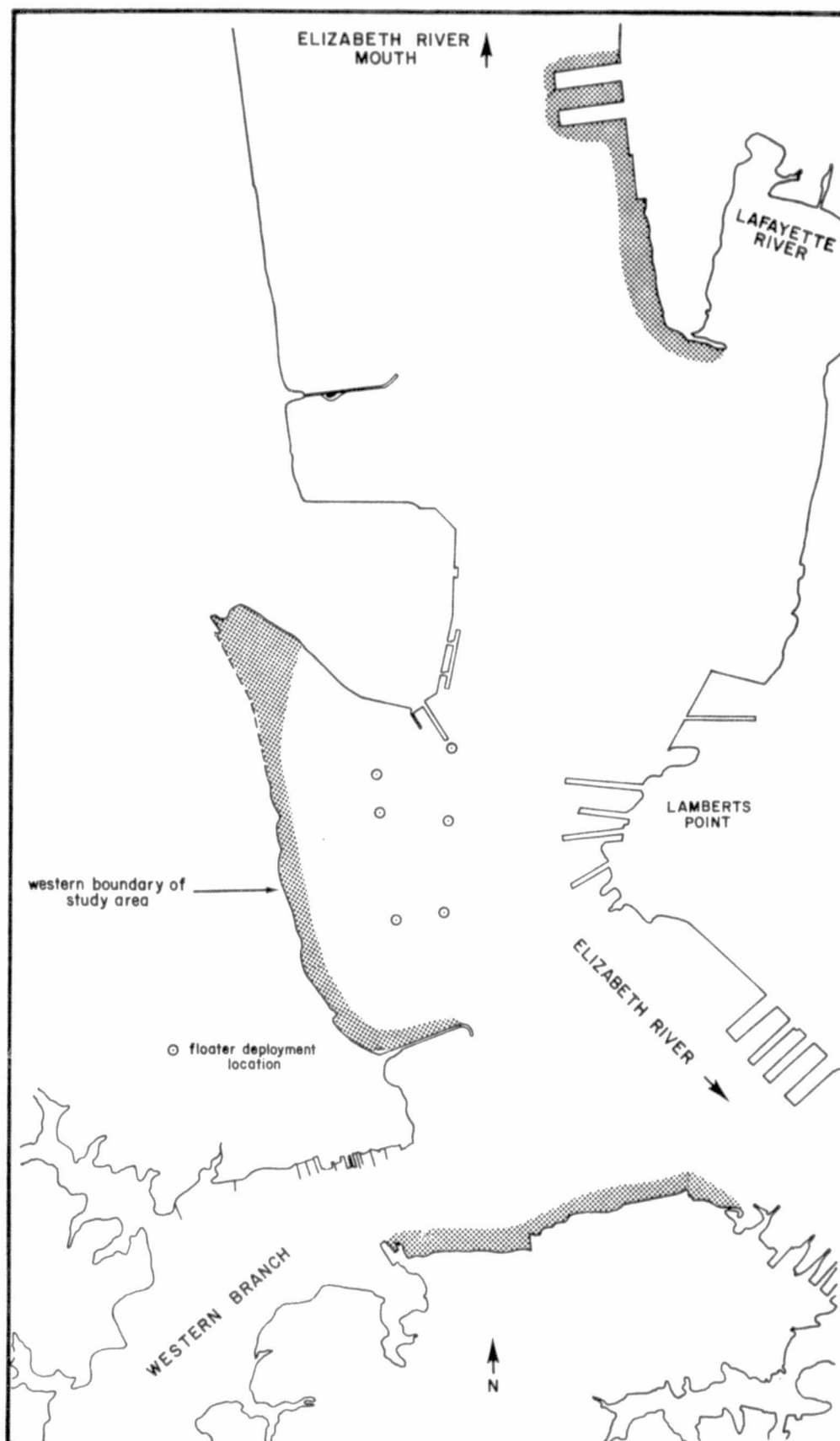
Figure 16. Elizabeth River oil slick beaching zones. Zones
of potential beaching danger shown in half-tone.

65

RESULTS

Some of the floaters did not go aground, but travelled up the channel of one of the branches of the Elizabeth River, generally, the one towards which the wind was blowing. This observation suggests the existence of an aiming or focusing mechanism which tends to keep the surface circulation confined to the channel of an estuary when the wind is predominantly along the channel. If true, then the behavior of the surface circulation is enough different for along-channel wind, compared to other wind directions, that significantly different behavior might be anticipated from an oil spill in a down-wind oriented channel. The results for this case were therefore reported to the user as a special case: estimates of the maximum excursion for surface water originating at the study area along any of the three main channels under a down-wind condition. This maximum excursion occurs when the tide and wind are in alignment for all of a half tidal cycle. The estimate was 5-6 km for all three channels, two upriver and one downriver.

Additional data available from the remote sensing consisted of photographic and visual observation of oil slicks. The Elizabeth River is the site of frequent oil spills and continual slicks from secondary sources. The largest slick observed during the four days of experiments was estimated to consist of several hundred gallons. The opportunity was thus available to examine directly the behavior of oil slicks under some conditions from

sources near the study area and to examine the relation between the slicks and the behavior of the dye drogues used to mark the surface circulation.

The most valuable observation from the study of the images containing both oil and dye drogues is related to convergence zones, similar to those which proved pivotal in the Newport News Point Study. Several of these zones were observed to concentrate oil. The result was that the slicks had a highly irregular and branched appearance. The dye drogues were observed to be caught up in the same convergence zones and found within the oil slicks. We conclude that dye drogues, in finding convergence zones, behave in a manner similar to oil slicks without any careful design and trimming for equivalent wind drag. Thus, the dye drogue results have a confirmed validity for use in evaluating oil spill hazard.

The observed convergence zones had an interesting behavior as they approached shore. They always became parallel with the shore, and when they beached, they did so over distances of about a kilometer within a short period. This behavior points to a strategy that can be followed in an effort to clean up oil spills. Extending the observations to a general case, it is possible to determine small linear areas which contain the highest concentrations of oil and to estimate the order in which these will come to shore and the time allowed before each one does.

The fluid phenomena observed in the imagery were both associated with sewage outfalls. In one case, the flow from the

outfall had created a depression in the river bottom, in conjunction with local sediment transport processes. The resulting depression refracted energy from the dominant waves, caused by ships in the channel, thereby determining the local patterns of sand bars. This phenomenon might serve as an excellent study area for some controlled sediment transport process experiments on a scale larger than can be obtained in a laboratory. The second phenomenon was observed around the large sewage outfall from the Lamberts Point sewage treatment plant. In some cases, a ring of lighter color water surrounds the source of effluent. This is almost certainly the signature of an internal hydraulic jump, with the relevant Froude number being related to the difference in density between the effluent and the receiving water and the rate at which effluent is being pumped into the system. The effect of this phenomenon on the initial mixing of the effluent is not clear, but it almost certainly has one. The ease with which it can be detected by remote sensing may make it a useful parameter to monitor the operation of an outfall on a routine basis.

SOLUTION AND ACTION

The current status of the user interaction associated with this project is that the report containing data, interpretation, and recommendations has been sent to NUS in a draft form for review, and accepted as received without comment. The Hampton Roads Energy Company is currently awaiting a hearing on its permit application. Until the permit has been issued, the exact user response will be difficult to determine.

SAVINGS, BENEFITS, COSTS

The NUS Corporation contracted with VIMS for several studies in connection with the oil refinery site evaluation. For the remote sensing component they contributed $6,024. The total cost to VIMS of the remote sensing study was $15,626 (see Table 8). Thus, the NASA grant contributed $8,056 or 57%.

The cost of alternate methods can be estimated from the fact that field work for this study was twice as extensive as in the earlier studies, and remote sensing costs were double those of the earlier studies (compare Table 8 with Tables 4 and 6). The costs of alternate methods would be about $36,000 (double the cost in either Table 5 or 7). Alternate methods would thus have been $36,000/$15,626 or 2.3 times as expensive as remote sensing.

With respect to benefits, it is of interest that earlier biological studies by VIMS of a different site led to its rejection. The Elizabeth River site, evaluated with the aid of remote sensing, is still under consideration; therefore, determination of remote sensing benefits is not yet possible.

TABLE 8.   REMOTE SENSING STUDY COST DATA, PORTSMOUTH OIL
           REFINERY

Personnel

    Field and Air
       15 man days @ $60/day   900

    Film Data Transfer to Charts
       15 man days @ $60/day   900

    Report to User
       20 man days @ $80/day   1,600

Vehicle

    Aircraft/Pilot
       30.6 hours @ $32/hr   979

    Boat
       4 days @ $75/day   300

Materials

    Dye
       100 cakes @ $20/cake   2,000

    Buoy Construction
       100 buoys @ $5/buoy   500

    Film and Processing   634
                               ————
                           7,813

Indirect Costs

    Methods Development and Overhead
       100% of direct costs   7,813
                               ————

                  TOTAL   15,626

4. HAMPTON BAR DREDGING

THE PROGRAM

The Newport News Shipbuilding and Drydock Company has been enlarging its shipyard for the past two years for construction of Liquid Natural Gas (LNG) carriers. The greater portion of the enlargement has been achieved by filling a shallow section of the James River upriver and adjacent to the previously-existing shipyard. For the fill material, several dredging operations have been conducted in Hampton Roads.

During one of the dredging operations, conducted in the Hampton Bar area, concern was voiced as to a potential impact of operations on shellfish grounds. Consequently, VIMS was asked by the shipyard company to monitor dredging operations, assess their localized effect on the shellfish grounds, and recommend operational changes to mitigate adverse impacts or prevent their occurrence.

Dredging was authorized by the Norfolk District of the U.S. Army Corps of Engineers. The permit allowed removal of two million cubic yards of sand. The dredging contractor was the Norfolk Dredging Company.

The potential impact of dredging has two aspects. One relates to the fine sediments introduced into the water column with the runoff of excess water from recovered fill material. VIMS decided that several factors relating to sediments needed to be considered: rate of release of fines, their subsequent history of movement and dispersal, and their tendency to accumulate in

locally significant quantities on the bottom where they might
cover inactive shellfish and other bottom dwellers. The second
aspect is possible water quality degradation. VIMS decided in
this case to monitor organics and depressed dissolved oxygen levels
resulting from the released material.

THE USE OF REMOTE SENSING

The monitoring program was chosen to have several compo-
nents: aerial photography of the surface plume of suspended
sediment, surface and subsurface water sampling for suspended
sediment concentrations and dissolved oxygen, and visual inspection
of shellfish beds on the bottom in the region adjacent to the
dredge site. Bathymetric profiling was conducted after cessation
of dredging to measure the physical changes and verify compliance
with the dredging permit details.

The aerial photography was selected as the only feasible
means for delineating the sediment plume. The surface samples
were intended to allow quantitative interpretation of the photog-
raphy.

The rest of this chapter considers only sediments because
remote sensing is useless for measuring oxygen levels.

METHODS

Aerial photography and associated sampling were conducted
on several dates during the periods March through July, 1974,
and late August, 1974, through February, 1975. Both oblique and

nadir views were obtained from a light aircraft with a Minolta 35 mm camera employing color film. During a flooding tide on 5 December, 1974, an overlapping series of nadir photographs was obtained with a Hasselblad 70 mm camera. A mosaic made from contact prints permitted accurate mapping of the plume in relation to known sediment concentration control points. Water samples were collected within one hour of the overpass along five transverse sections crossing the plume at varying distances from the emission source. The resulting concentration data were then compared with the plume boundary drawn from the mosaic.

RESULTS

Figure 17 shows imagery of the dredge operations. Figure 18 shows the plume boundary derived from a color mosaic on one of the study dates, and the corresponding surface concentration data from Boon and Byrne (1975).

A tighter correlation of surface and photo data is inappropriate since the surface sampling took an hour to complete. This illustrates the fact that traditional surface methods are difficult to compare directly with remote methods because only the remote data are synoptic.

Results from the other parts of the monitoring program are contained in the report to the Newport News Shipbuilding and Dry Dock Co. by Boon and Byrne (1975).

In general, the aerial photos provided an indispensable view of the dredge plume under varying tidal conditions. The

Figure 17. Imagery of dredge operations over the Hampton
            Bar. Copies of original color photography.
            Top: oblique view. Bottom: nadir view.

FLOOD RUN 12/5/74
SUSPENDED SEDIMENT CONCENTRATIONS (mg/l)

Figure 18. Dredging plume and suspended sediment concentrations during flood tide. Surface sampling for suspended sediment concentrations consumed one hour. Plume boundary derived from imagery.
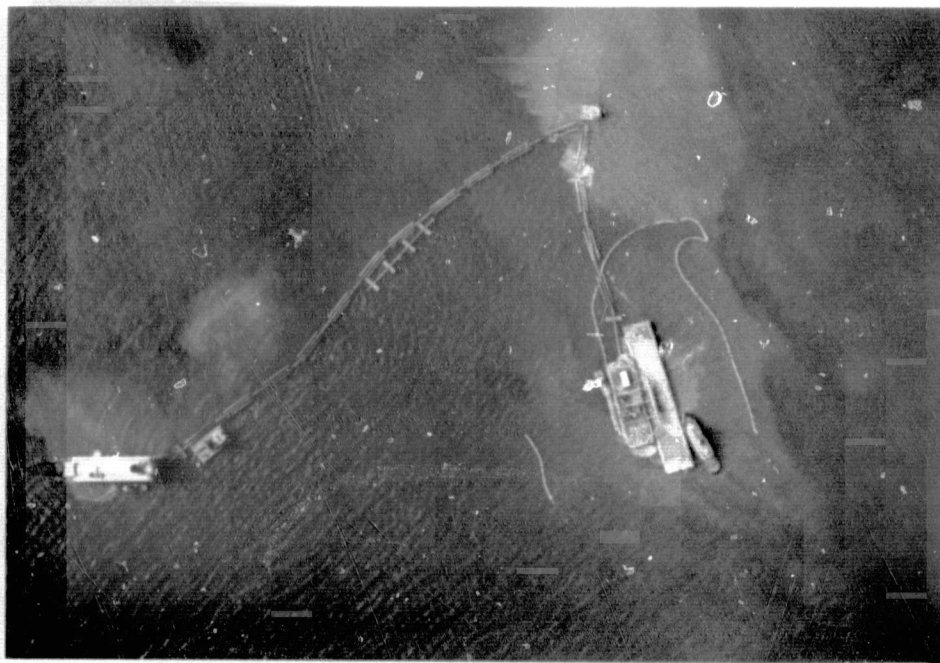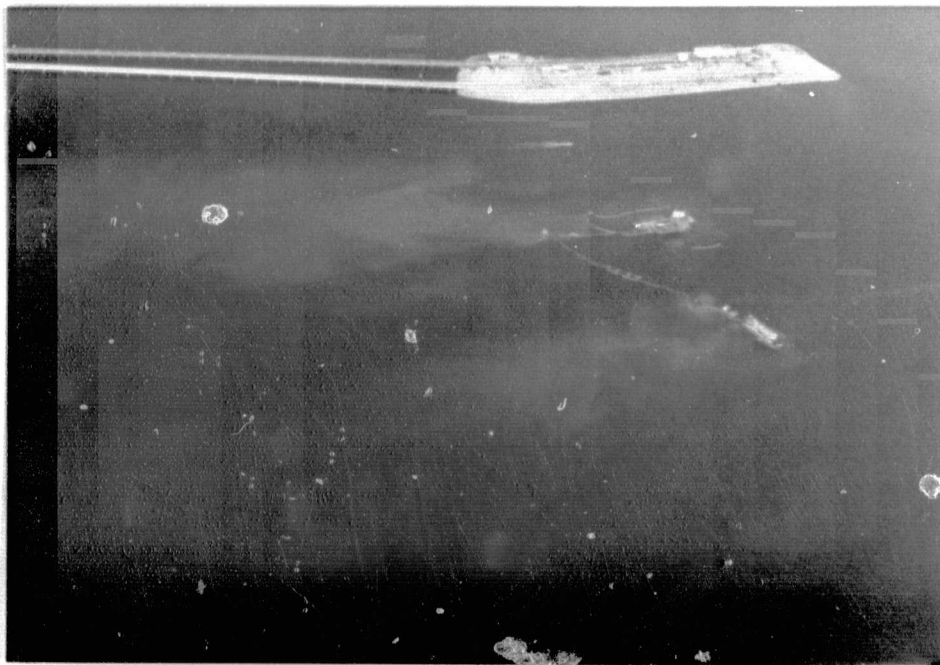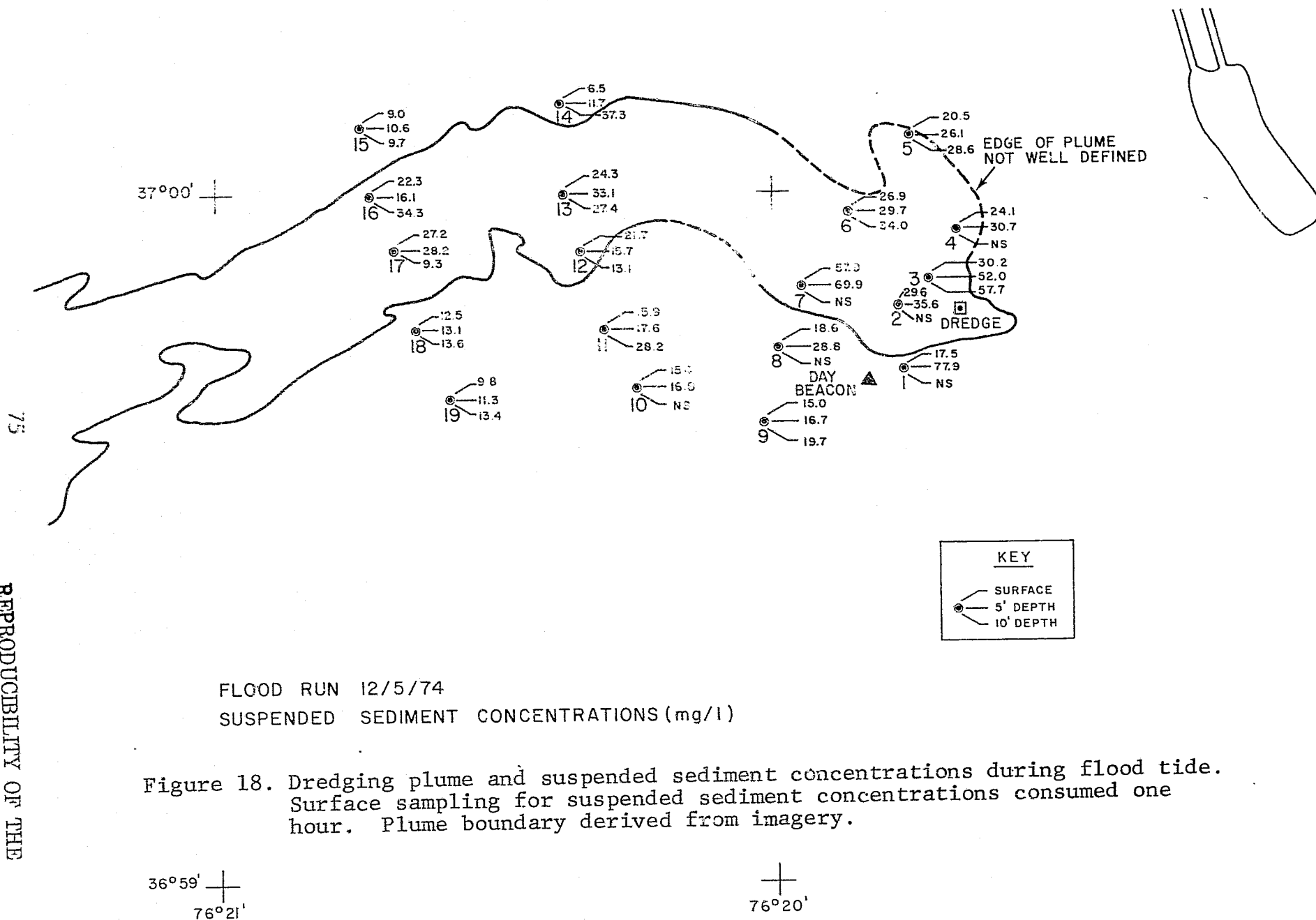
aerial photo results of 5 December confirmed quantitative impressions based on all surface sampling data. In particular the aerial photography demonstrated the ineffectiveness of the "silt curtain" used by the dredging company to satisfy regulations.

SOLUTION AND ACTION

VIMS biologists recommended that dredging activity which resulted in silt accumulations on shellfish beds should be prohibited when bottom water temperatures reached 50°F or less. The rationale behind this recommendation is that most benthic organisms have sharply reduced metabolic rates below 50°F and cannot free themselves from any overburden of sediment once they are in a dormant state.

Aerial and surface observations led to the conclusion that no significant bottom siltation would occur in shellfish bed regions during ebb tide. The dredging plume generated during ebb tide normally progressed toward the east where deep water and high velocity effectively mixed and dispersed the suspended sediment load within the plume. Turbulence also tended to reduce the rate of settling of fine sediments, keeping them in suspension over greater distances. Consequently, no restrictions on dredging were recommended for ebb tide periods.

For flood tide periods, however, there was a clear danger of excessive accumulation of silt over shellfish beds. VIMS therefore recommended that flood tide dredging be restricted to

warm water conditions. Surface and bottom water temperatures were then measured at four-hour intervals, and the critical temperature of 50°F was reached on November 28, 1974. The restriction to ebb-tide-dredging-only went into effect shortly thereafter, and continued until the project's termination on February 10, 1975.

SAVINGS, BENEFITS, AND COSTS

Aerial photography provided an indispensable overview and was considered necessary for successful solution of the problem. The correlation of surface suspended sediment values with the aerial photography allowed all oblique and nadir photographs to be properly utilized in reaching conclusions; particularly, a substantial plume is evident on aerial photographs with relatively low (in this instance) suspended sediment values. Consequently, the presence of a plume on a photograph does not automatically justify the conclusion that suspended sediment levels are injurious.

Newport News Shipbuilding and Drydock Company paid for nearly all costs including most of the aerial photography through a contract for $40,000. A small portion of aerial photography costs was borne by this NASA grant.

An assessment of the benefit to the shellfish industry by the action taken would require assessment of the economic value of the grounds involved. Such data were not available.

5. WINDMILL POINT ARTIFICIAL MARSH

THE PROBLEM

The U.S. Army Corps of Engineers reviews, monitors, and
regulates dredging in navigable waterways. An acute problem
in recent years is disposal of large volumes of dredged material.
A new solution of this disposal problem proposed by the Corps
has been using the spoil for the creation of potentially productive
wetlands. The Corps proposes to construct diked areas which are
then filled with dredged material and subsequently become stabil-
ized by marsh grasses. This artificial marsh concept is presently
being investigated in several locations in the eastern United
States.

A site at Windmill Point on the James River was selected
by the Corps as one of the demonstration experiments (see site 5
on Figure 2). A comprehensive investigation of environmental
impact is central to proper testing of the concept, in that the
goal is a beneficial use of dredge spoil. Consequently, the
Corps included in its investigation a study of the impact of
suspended sediment released during filling of the diked artificial
island. The Corps (Vicksburg Waterways Experiment Station) asked
VIMS to assist in this study by selecting water sampling locations
in accord with tidal circulation in the region of the site. The
Corps requested in December, 1974, that VIMS respond within two
to three weeks.

The Corps is particularly interested that the artificial
marsh not accelerate (apparent) erosion along the adjacent

shoreline, because of the presence there of the Flowerdew
Hundred plantation archaeological dig site.

THE CHOICE OF REMOTE SENSING

The desired short response time immediately reduced the
number of methods which could be used. A current meter study
was eliminated from the alternatives because of complexity, cost,
and scheduling conflicts. A drift card study was eliminated
because cards large enough to be easily resolved on images suffer
wind drag, and without sequential imagery they yield only desti-
nations not trajectories. Surface retrieval of large numbers of
cards is difficult without aerial spotting and is expensive in
boat time. The remaining alternative was a remote sensing dye
buoy study. It was perceived as ideal because it is inexpensive
and easily accomplished, the technique was in active use, and the
data reduction phase is extremely rapid.

METHODS

Water mass movement was traced by sequential aerial photog-
raphy of free floating buoys emitting green fluorescein dye.

Two studies were conducted, one on 15 January 1975 for
the flood half-tidal cycle, and one on 22 January 1975 for the
ebb.

On each day releases were made from two locations midway
between the dike and the Windmill Point shoreline throughout

the one-half tidal cycle. Releases were made at approximately one hour intervals. This technique permitted the determination of the current vectors throughout the tidal cycle, as well as the maximum excursion of the water mass. The atmospheric conditions on January 22, 1975 (ebb) were not good for photographic tracking; therefore, redundant data were collected by the dye release boat, consisting of successive fixations of buoy positions by horizontal sextant angles. This supplementary technique is very time-consuming, and risks the loss of data, as it is difficult if not impossible to find low-wind drag buoys which have dispersed over a large area.

Nominal altitude for photography was 5,000 feet (scale 1:30,000) which produces a 70 mm frame covering approximately one square statute mile. Over one-half of this study, however, was photographed at 3,000 feet (1:18,000) because of intervening cloud cover. Citizens Band radios were used to establish a ground-air link to insure proper correlation of boat and aircraft operations.

Processed color positive transparency film was carefully viewed on a light table, and aircraft and boat notes used to identify the floating buoys visible in each flight line. A Bausch and Lomb ZT4 Zoom Transfer Scope at NASA Langley Research Center was employed to transfer buoy image points to 1:24,000 scale topographic base maps.

Color prints from the 35mm camera were sorted by flight line and assembled into mosaics to illustrate sediment plume behavior. Figure 19 is a copy of one of the mosaics.

Figure 19.   Imagery of Windmill Point artificial marsh.
             A mosaic of copies of original color
             photography.   A plume of suspended sediment
             emanates from the site.
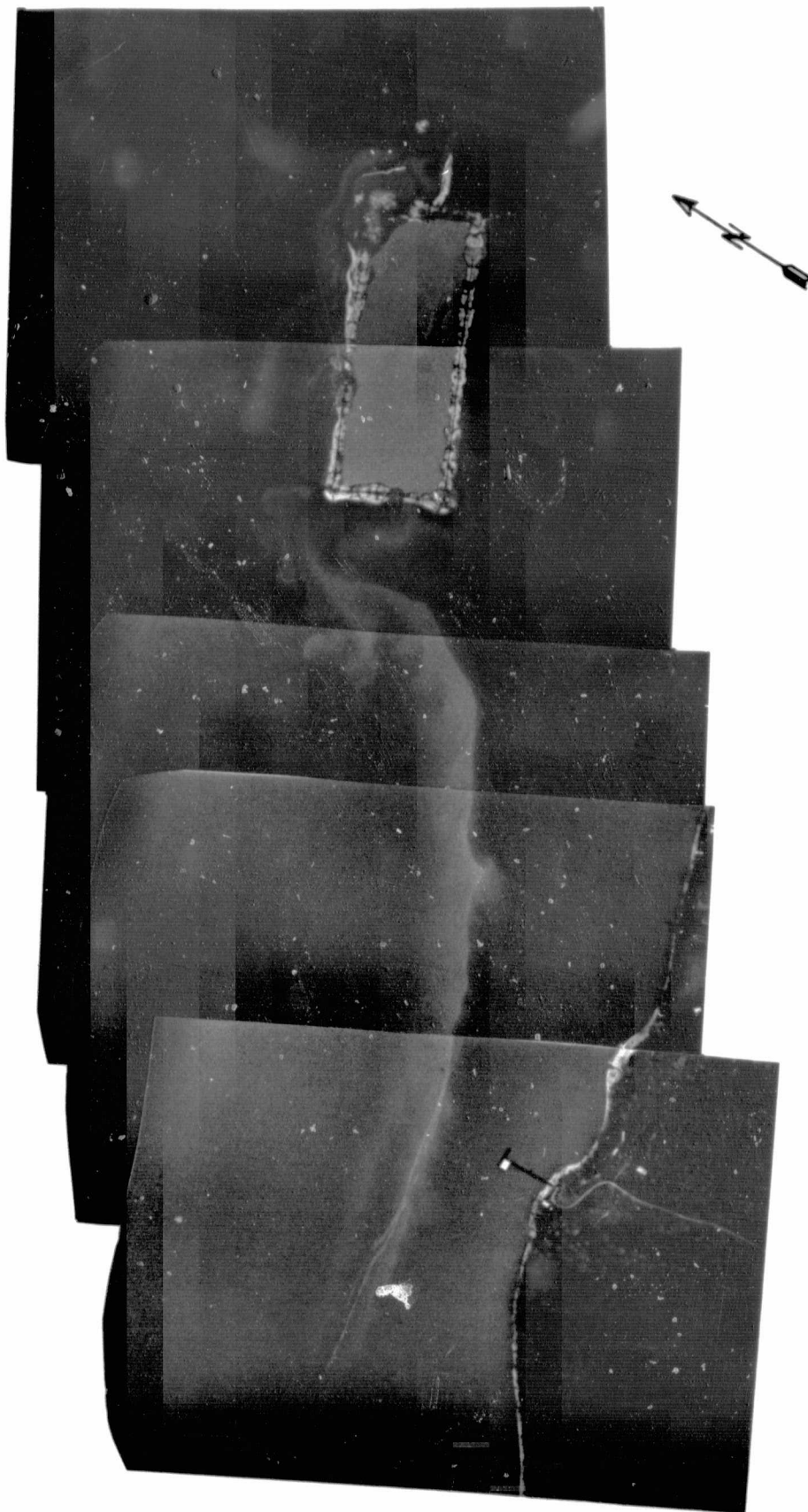
Dye markers deployed during the ebb study (January 22) were not always visible from the air due to low ambient light levels (the dye fluoresces when activated by sunlight) and low solubility of the dye in cold water. (The problem of low solubility has since been rectified via modification of the dye cake chemical recipe. See chapter 2 in Part Three.) Positions of the buoys were in this case determined by sextant readings on recognizable landmarks, and plotted on the topographic sheets.

RESULTS

Photomosaics of the imagery were constructed for the flood and ebb tidal phases. The mosaics and a report of the tidal trajectories were transmitted to the Corps (WES) project manager in the first week of February, in time for utilization in planning the required sampling design. The pathway of the spoil effluent was readily determined as the dredge was pumping material onto the site (in construction of the dike) during the overflights. These turbid plumes sufficed for first order analysis. Analysis of dye marker drogues corroborated the analysis of the turbid plumes.

The results of the flood cycle portion of the study are shown in Figure 20. Positions of the buoys are shown at times indicated and the current velocity is figured as the trajectory length divided by the elapsed time. The buoys used in this portion of the study had no identifying markers and they were soon lost due to low light conditions. However, examination of
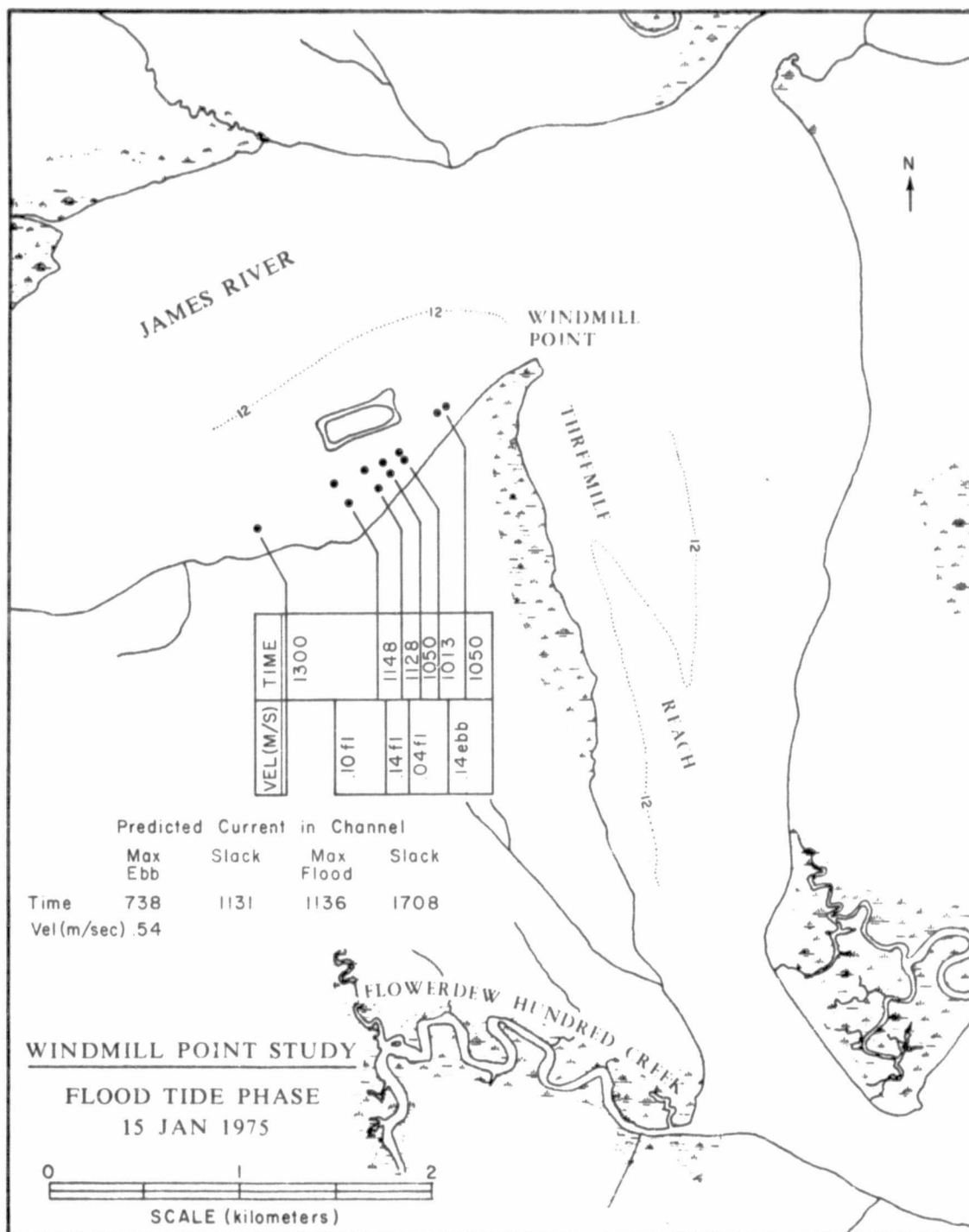
Figure 20. Windmill Point flood tide dye tracks. Two dye
buoys were released at 1050.

the compiled photomosaic indicates the turbid plume was confined shoreward of the 12-foot depth contour. There was little trace of the plume more than 2.5 km upriver of the dike, at which point the plume was a thin ribbon near the shore.

The results of the ebb tide phase study are displayed in Figures 21a through 21g, which show the trajectories of buoys released at intervals from the artificial marsh. The trajectory between surveyed positions represents a best placement using observations made in the field, and sediment plume behavior from the photomosaics. The figures show each marker in order of release at the time shown at the terminus of the trajectory closest to the dike. The maximum excursion is indicated by buoys 1A, 1B, and 1X. Buoys 1A and 1B are seen to reverse their direction after slack before flood. Buoy 3B was lost after deployment due to poor visibility near dusk.

Both the buoy trajectories and the excursion of the turbid plume indicate the water mass movement from the spoil site was limited to the western half of the river between Windmill Point and Flowerdew Hundred Creek along Threemile Reach.

In summary, the remote sensing study has indicated the expected trajectories of spoil effluent from the artificial marsh site for single ebb and flood phases of the tide.

SOLUTION AND ACTION

A brief report with photomosaics was transmitted to the Corps (WES) in early February, 1975. The project manager utilized

WINDMILL POINT STUDY

EBB TIDE PHASE
22 JAN 1975

JAMES RIVER

FLOATER 1A

N

1133
WINDMILL POINT

THREEMILE REACH

FLOWERDEW HUNDRED CREEK

.643
1126
1122
.806
.500
1110
1058 .246 m/s
.635
1210
.393
1235
.422
1335
.113
1540 .027
1432

0   1   2
SCALE (kilometers)
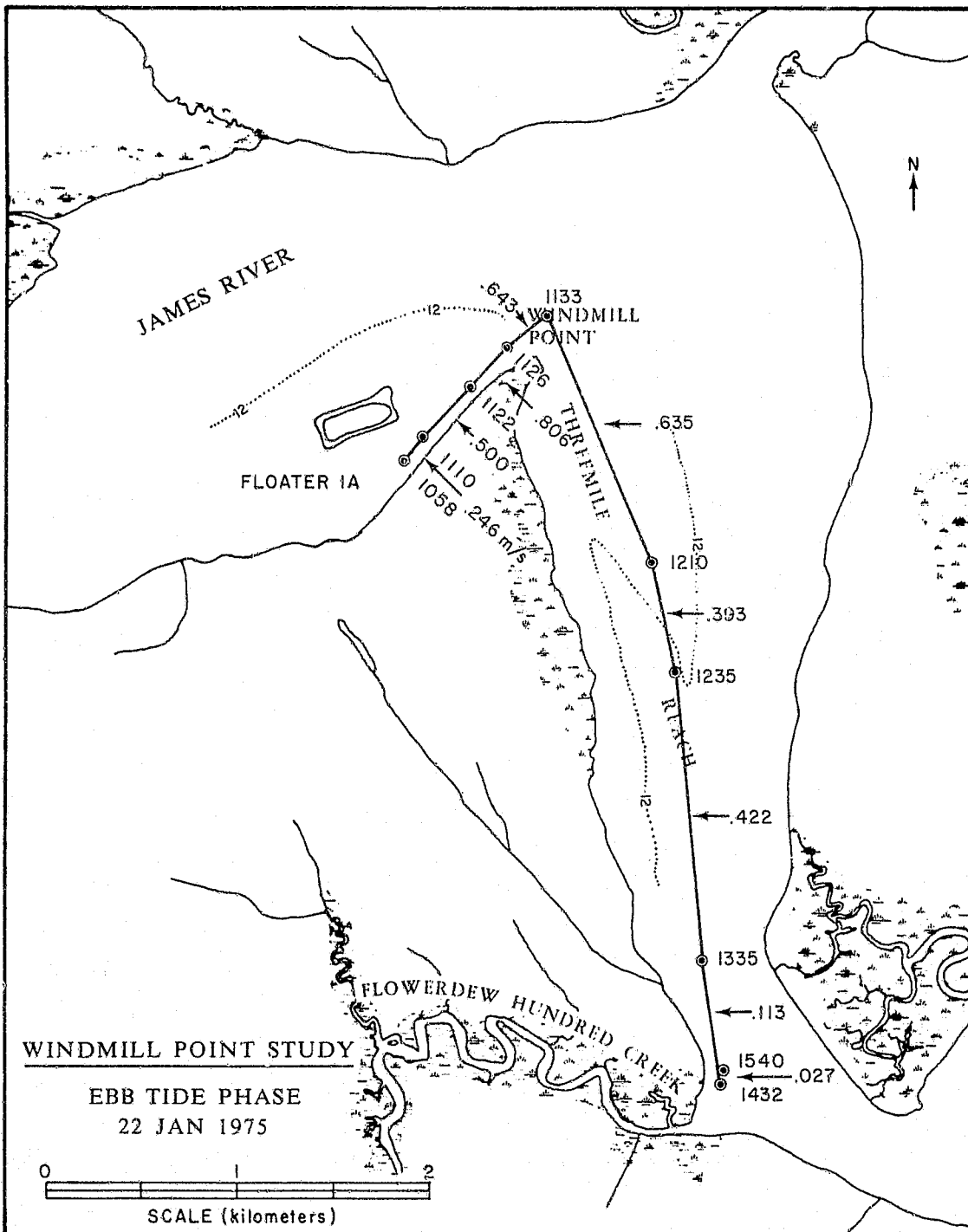
Figure 21. Windmill Point ebb tide dye tracks. Parts a
through g show trajectories of buoys released at
intervals from the marsh site.

85

Figure 21b.

JAMES RIVER

WINDMILL POINT

1217

.667

.469

THREEMILE

1150
FLOATER IB 1140
100 m/s

1253

.298

REACH

1342
.282

1441

FLOWERDEW HUNDRED CREEK

WINDMILL POINT STUDY

EBB TIDE PHASE
22 JAN 1975

1540's
APPROX.
POSITION

0   1   2

SCALE (kilometers)
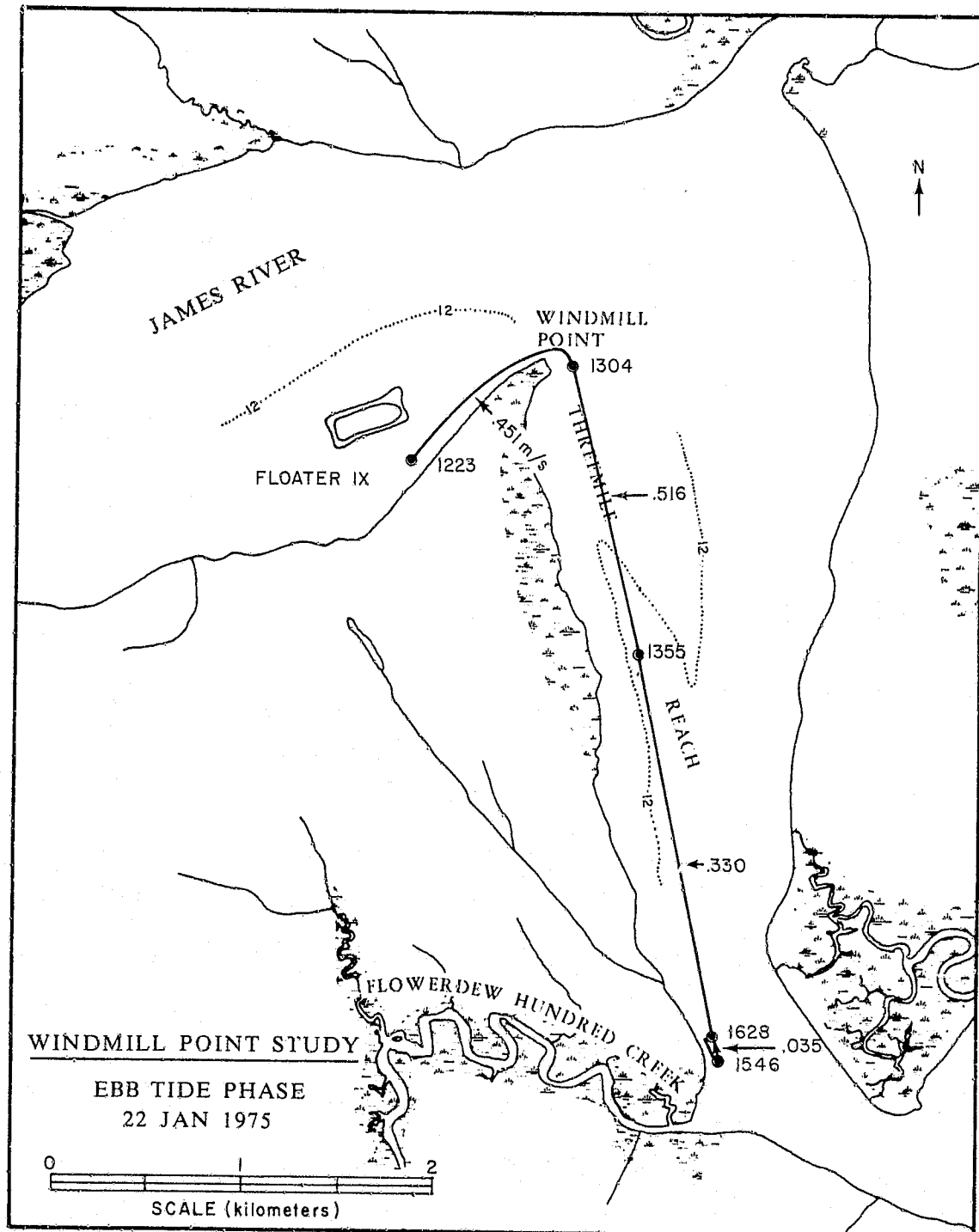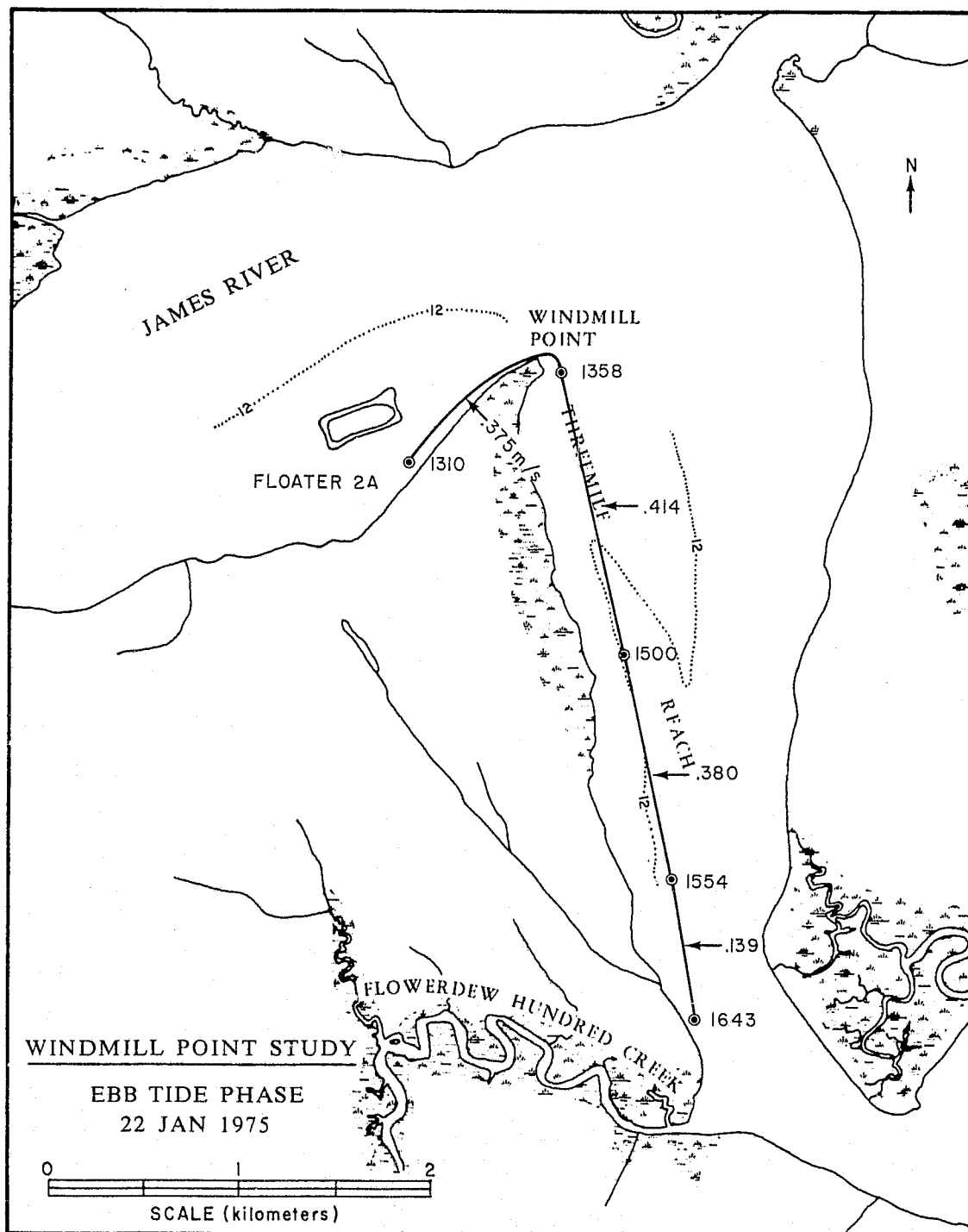
Figure 21c.

Figure 21d.

Figure 21e.

Figure 21f.

JAMES RIVER

WINDMILL POINT

1608

FLOATER 3A

1523

1.55 m/s

THREEMILE REACH

FLOWERDEW HUNDRED CREEK

WINDMILL POINT STUDY

EBB TIDE PHASE
22 JAN 1975

0   1   2

SCALE (kilometers)

Map labels: JAMES RIVER, WINDMILL POINT, FLOATER 3B, 1614, THREEMILE REACH, FLOWERDEW HUNDRED CREEK

WINDMILL POINT STUDY

EBB TIDE PHASE
22 JAN 1975

0   1   2
SCALE (kilometers)
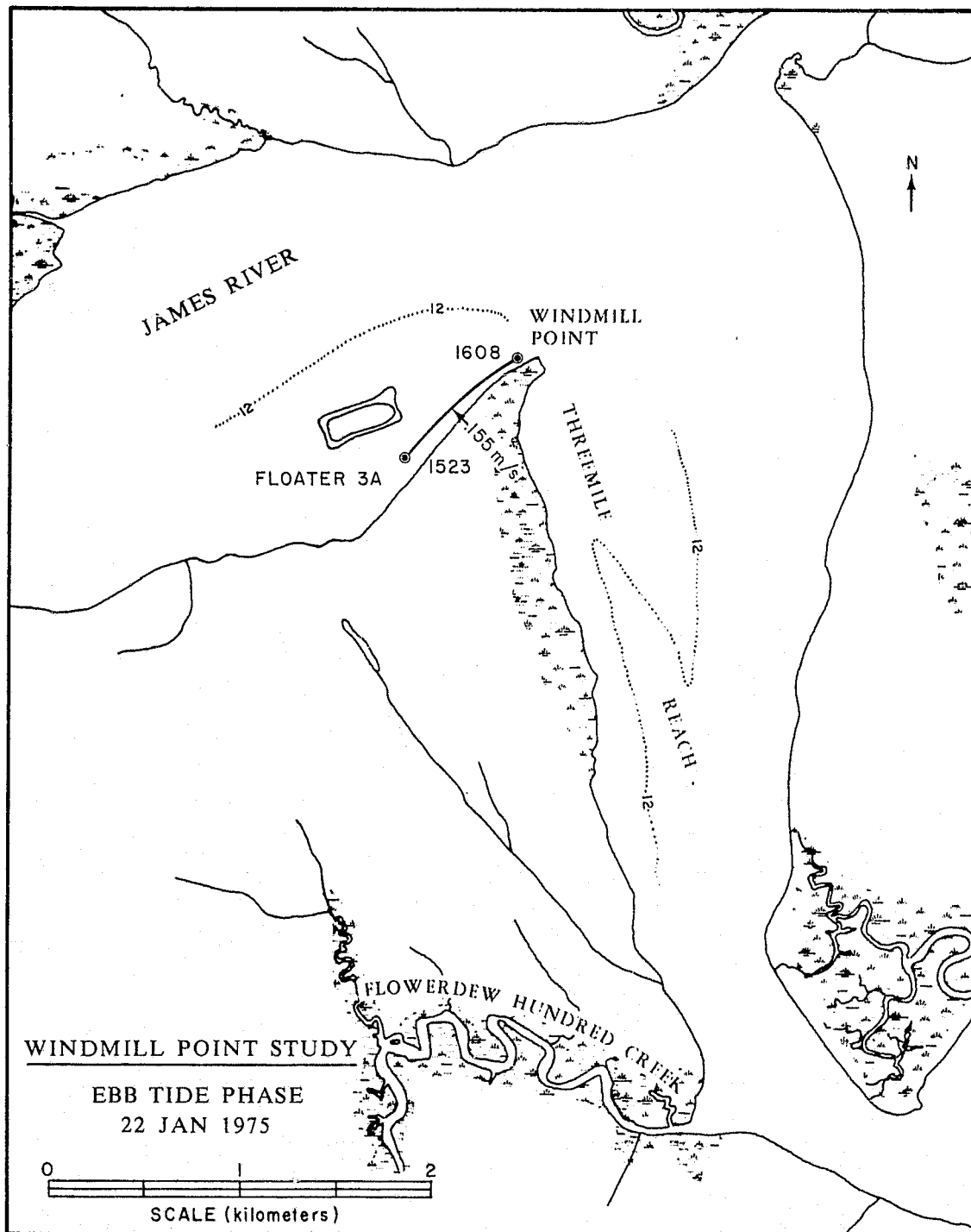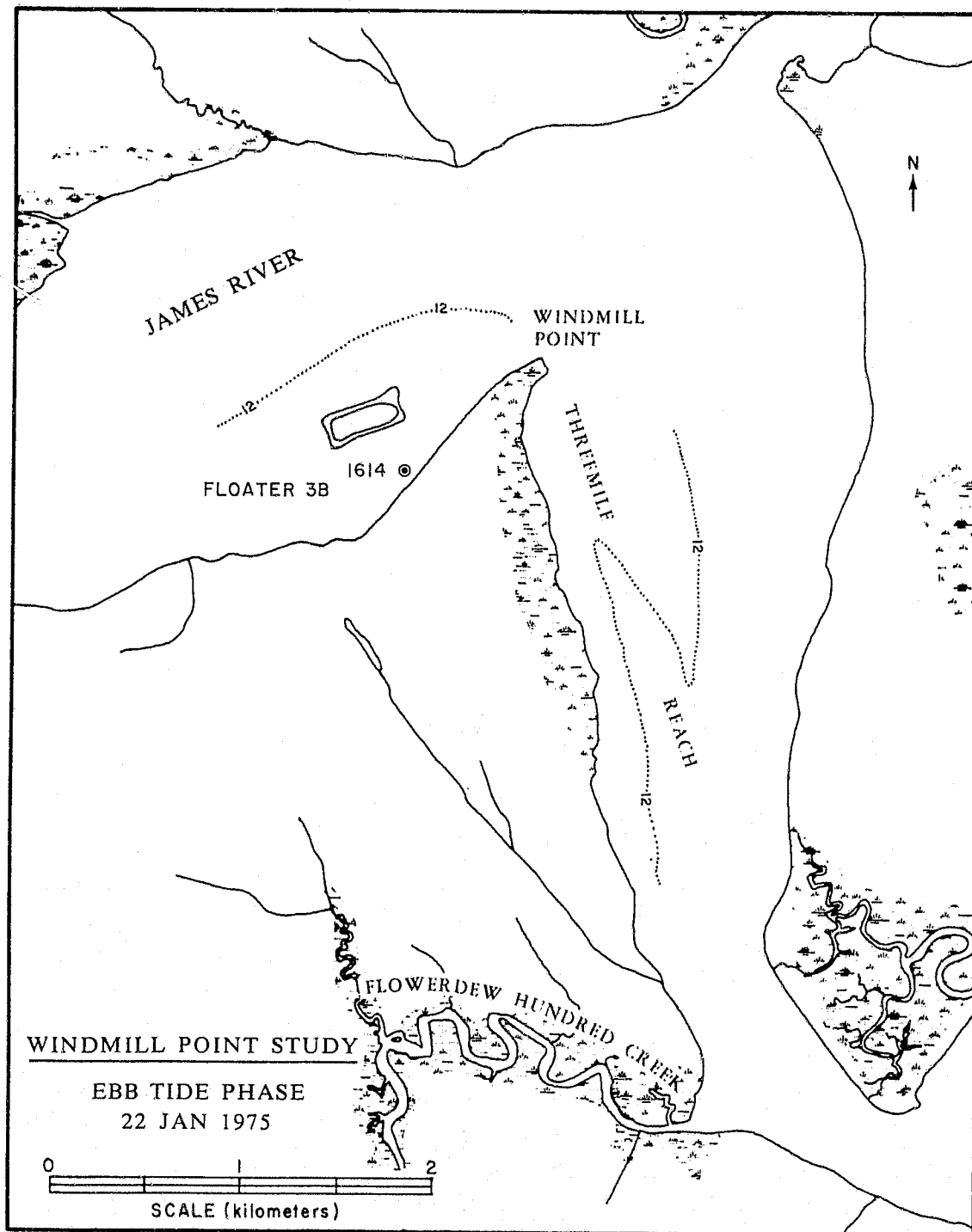
Figure 21g.

the data and interpretation in selecting water sampling locations, and the Corps study of suspended sediment impact has proceeded. The Corps (Norfolk District) has since obtained controlled photogrammetric surveys of the artificial marsh proper. Pioneer marsh vegetation established itself naturally on the island in spring 1975, and the Corps is supplementing this natural vegetation with spikes of planted marshgrass. The vegetation has made the island newly visible on LANDSAT images, MSS 6 and 7, as of 9 June 1975 (unlike the Craney Island dredge disposal site, which is devoid of vegetation and highly reflective in all 4 MSS bands, the artificial marsh is highly reflective only in MSS 6 a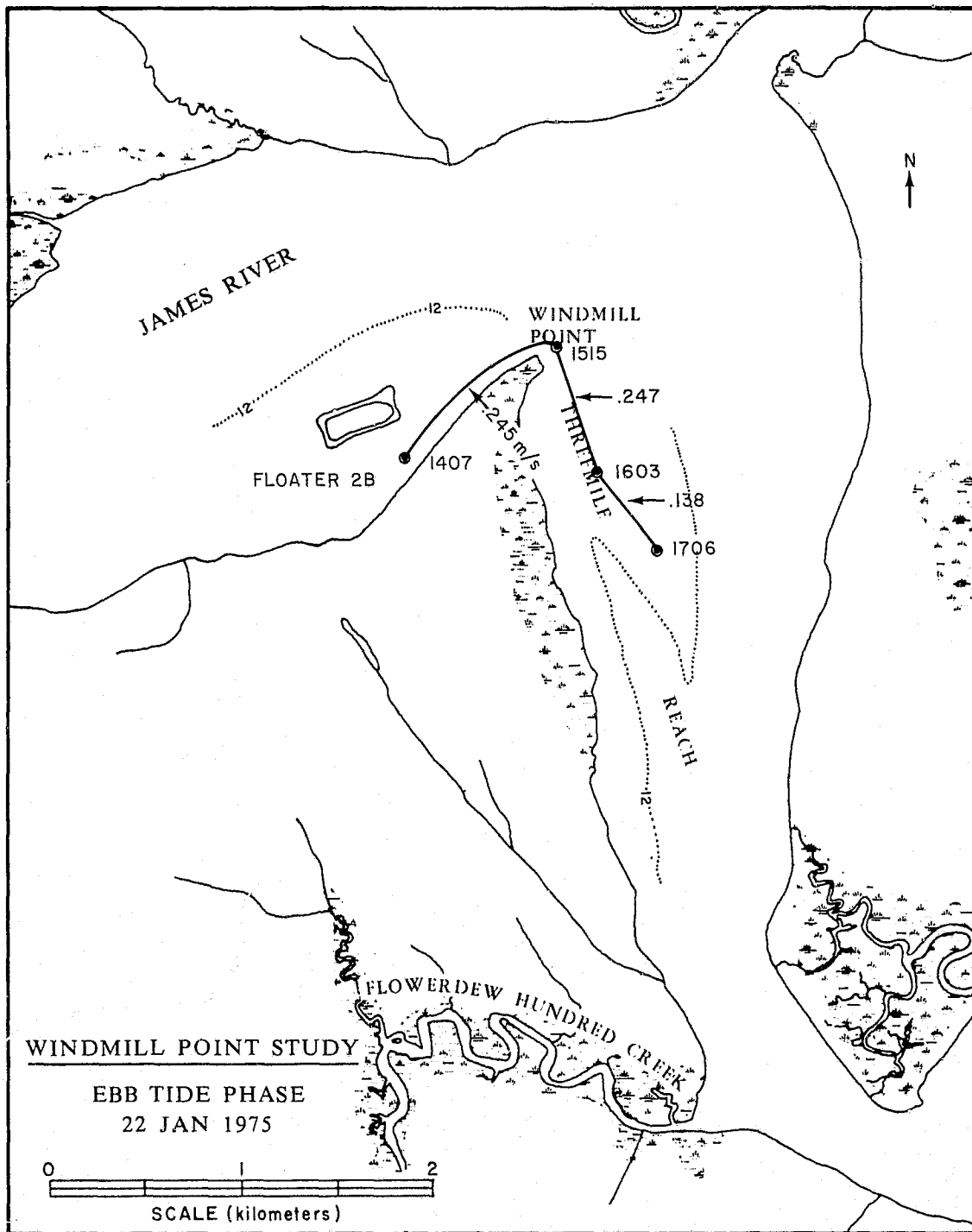nd 7, indicating the spoil is covered by vegetation). Corps evaluation of the artificial marsh concept is continuing. A letter of appreciation to VIMS from the Corps is included in Appendix A.

SAVINGS, BENEFITS, AND COSTS

Cost of the study for VIMS was similar to costs of other studies described in earlier chapters. This grant supported all costs. The cost ratio of alternate methods would be similar to examples in earlier chapters, that is, roughly twice as expensive as remote sensing.

6. NEWPORT NEWS SHIPYARD WATER QUALITY

THE PROBLEM

Shortly after the Newport News Point study, the Naval Ship Research and Development Center, Department of the Navy, asked for a set of the Newport News photos. The problem concerned water quality in the vicinity of the Newport News Shipbuilding and Drydock Company, which is in the field of view of the photography taken during the Newport News Point Circulation Study. A set of photographs was quickly produced in 35 mm format and sent to the Navy.

A letter has been received in acknowledgement from A.L. Waldron, Head, Environment and Firefighting Division, Code 285, of the Annapolis Laboratory of the Naval Ship Research and Development Center which said, in part,

"The information furnished by these photographs will be of great benefit in helping us to explain certain naval material problems associated with new naval construction at the Newport News Shipbuilding and Drydock Co. yards" (see letter in Appendix A).

We note that the original contact with the Navy was unplanned, being the result of general advertising rather than a specific approach to the Navy. Moreover, the imagery desired by the Navy was fortuitously obtained in the course of a different study. This coincidence emphasizes the fact that, in estuarine and port areas, a large number of potential users are crowded into a confined space.

NEW DEVELOPMENTS

Sometime after transfer of the set of photographs, early in 1975, the Navy contracted with VIMS to conduct water quality monitoring and chemical analysis of waters adjacent to the shipyard. When significant events occur, aerial imagery will be obtained to delineate circulation patterns. Existing NASA high altitude imagery is meanwhile being examined for information on circulation patterns in the vicinity of the shipyard.

7. PIG POINT SEWAGE OUTFALL

THE PROBLEM

As part of the effort to upgrade sewage treatment in the Hampton Roads Area, the Hampton Roads Sanitation District Commission (HRSDC) has proposed a sewage treatment plant in the vicinity of Pig Point on the Nansemond River. The engineering team of "McGaughy, Marshall, and McMillan-Hazen and Sawyer: A Joint Venture" was commissioned by HRSDC to formulate specific plans and evaluate the environmental impact of such a treatment plant. The engineering team asked VIMS to conduct a dye dilution study to assess the microbiological and BOD impact on a proposed sewage outfall site. VIMS has performed several experiments and evaluated circulation data in the area of the proposed outfall (Fang and Neilson, 1975). Remote sensing studies are continuing in the current grant year.

Last year's experiments consisted of point releases of Rhodamine dye followed by boat-borne fluorometry to determine the dye distribution over several tidal cycles (Kuo and Jacobson, 1975). Surface dye concentrations over time were analyzed to determine a dispersion coefficient. The coefficient permits a prediction of the distribution of a non-conservative pollutant released from the proposed outfall.

Ideally, each boat traverse over the study area should be completed in no more than a few hours, in order that the measurement be validly associated with a given period of slack water.

This period and the maximum boat speed determine a total boat travel distance. This distance was arranged in a path designed to cover the study area uniformly, and resulted in a resolution for the experiment (mean distance from a path, for example) of about 1 km. Obviously, this poor resolution is bound to permit important details of circulation patterns to be completely overlooked.

THE COMPLEMENTARY USE OF REMOTE SENSING

In order to obtain higher-resolution data from the experiment in the region around the point source, a series of aerial photographs was obtained of the readily visible dye from the source shortly after release. The photographs were processed and delivered to the VIMS investigator in charge of the dye study. While the investigator acknowledged the photographs and reviewed them, he was not yet confident in using them quantitatively for his report, and his reporting schedule did not leave enough time for careful densitometry to be completed. The photographs were consequently used only in a qualitative way. HRSDC was shown the photographs and acknowledged their value in providing a detailed view of conditions prevailing at the time of the study, allowing them to conclude that the fluorometric results were valid.

NEW DEVELOPMENTS

Recently, HRSDC informed VIMS that it desired to put the outfall at a slightly different location than planned earlier. Because of the divergent nature of circulation between the old and new suggested locations, a simple extrapolation of results from the earlier dye studies is considered by VIMS to be invalid. Permission has been obtained for a remote-sensing/dye-buoy study to complement the earlier dye-release/fluorometry study. The remote sensing study has been accepted as an alternative to another dye-release study because it is much cheaper and it will delineate circulation patterns much better.

With respect to the investigator's lack of confidence in densitometry, a remote sensing demonstration experiment is planned for fall 1975. Densitometry will accompany the usual fluorometric analysis on a different dye-release study planned for the Piankitank River.

COSTS

The engineering team, with HRSDC approval, contracted with VIMS as of March, 1974, for $15,000 of dye and circulation studies in the region of Pig Point. The additional study for summer and fall of 1975 involves add-on funding.

8. COASTAL RESEARCH PHOTOGRAPHY

Ongoing research programs within the Department of Geological Oceanography at VIMS are directed at beach and sand morphological dynamics. A particular area under current study is the coastline between Virginia Beach and the North Carolina border. In 1974 the VIMS remote sensing laboratory was requested to provide low altitude photography of this coastline, to complement a photographic sequence over several years. Color photography was obtained in December, 1974 in 70 mm format using the Hasselblad camera, from an altitude of 760 m.

This photography is still under study. Dr. Victor Goldsmith and assistants at VIMS have since arranged to obtain copies of earlier NASA Wallops Flight Center color infrared photography of the same coastline. The objective is to measure dune heights, topographical orientation, and strike of the slip face, all as a function of time since 1969. Development of procedures is currently underway, with purchase of a stereometer (parallax bar), and training of assistants in photogrammetric procedures including the use of a Kelsh plotter at VIMS.

A second area of interest is Fisherman's Island, on the north side of the Chesapeake Bay mouth at the southern end of the Eastern Shore. In 1974 Mr. Mark Boulé of VIMS asked the VIMS remote sensing laboratory to obtain color photographic coverage of Fisherman's Island. The photography was obtained in December, 1974. A map has been drawn of vegetative communities, which is being interpreted for clues as to the geological history of the island.

PART THREE: METHODOLOGY

1. FAST-RESPONSE AERIAL AND FIELD CAPABILITY

RELIANCE ON INTERNAL DATA COLLECTION

With a clear need for a siting system to be capable of rapid response, one of the principal design criteria for a remote sensing siting system is that data acquisition, reduction, and analysis be streamlined for a turnaround time of one to six months. Remote sensing data acquisition can be achieved in sufficiently short times by commercial firms on a subcontract basis. Or, VIMS can carry out data collection itself. VIMS has preferred to use its own capability (when the instrumentation needs are not excessive), because this avenue is cheaper, faster, easier to coordinate, and enhances our future capability for meeting needs of the Commonwealth.

At times, however, VIMS needs expensive and elaborate instrumentation, such as infrared scanners, which are presently too expensive for VIMS to acquire and operate. To avoid the high expense of sub-contracts with commercial firms, our best recourse is then to obtain assistance from NASA or other government agencies. However, coordination is then more involved, and the turnaround time is significantly lengthened.

CONSTRAINTS FROM TIDES AND WEATHER

Circulation analysis for resolving siting questions requires hourly data over both flood and ebb tide conditions. Whereas the hydrographic survey can obtain data in darkness as

well as light, and thereby obtain circulation data for both halves of the tidal cycle in a continuous experiment, the necessity of daylight conditions for aerial photography requires that flood and ebb portions of the tidal cycle be obtained in missions on different days. The days must usually be separated by a week to allow the 6.5 hour duration of a tidal half-cycle to advance from one-half in daylight to the other half in daylight. Already it can be seen that the remote sensing team must be poised to act twice as often as the hydrographic survey.

The remote sensing team also must be poised to act quickly to take advantage of good weather. In the lower Chesapeake Bay region, weather is variable on an intra-day basis. Weather conditions and projections must be assessed as late as sunrise on the day of an intended mission. Seasonally, summer weather is generally humid and hazy. Spring and fall weather are much clearer. Winter weather is often clear but days are shorter. During the summer of 1974, the remote sensing work force was poised for action for weeks at a time, and activated often, but missions were not successfully completed on all occasions because of variable weather. The ratio of completed missions, to partially complete, and to actively ready, was roughly 1:3:15. Missions were not conducted on weekends principally because the VIMS supporting staff in communications and waterfront operations was not available. Thus, considering only weekdays, we see that these ratios permit roughly 4 missions, that is 2 sites, in 2

months, when the project personnel are poised daily, and activated
on the average 3 times every 2 weeks. It is obvious that being
poised daily will cause fatigue and demoralization if each day of
readiness involves very much preparation. Consequently, we have
arranged to be ready with minimal effort and in a short time.
Our goal is a 2-man 2-hour preparation effort, for a mission in-
volving up to 10 people.

DEPENDENCE ON AERIAL PHOTOGRAPHY

The most important remotely-measurable indicators of cur-
rents and circulation are water color and water temperature
(Munday, et al., 1971). There are cases when the two variables
are not independent (Wachapreague Inlet studies, annual report,
Zeigler et al., 1974). When permitted by the goal, the variable
of choice is water color, since aerial photography is easier and
cheaper to obtain than infrared scanner imagery. Furthermore,
many circulation studies require water-mass marking by dyes and
drogues. Only photography is suitable for imaging dye markers.
For pinpointing locations of drogues, either radar or photography
is suitable. (There has been mention of specially constructed
hot-target drogues to permit infrared imaging, but these would
be relatively impractical.) VIMS and NASA/WFC have shown the
suitability of radar (Welch and Haas, 1973), but aerial photography
is simpler and can be obtained by VIMS itself.

The necessary aerial photography is obtained with a Cessna
Cardinal aircraft operated by Omni Enterprises of Gloucester,

Virginia. The aircraft has a nadir-looking hole in the fuselage. The pilot and aircraft are available almost on an immediate-call basis. The airport is ten miles away. When the pilot is unavailable, licensed pilots on the VIMS staff can be used.

The camera in use is a Hasselblad 500 EL/M 70 mm electric-drive camera with a 50 mm Distagon f/4 wide angle lens. This camera is on loan from the U.S. Coast Guard. For 70 mm color photography, Kodak high-speed Ektachrome ER Film 5257 (ASA 160) is used with a haze filter. The usual exposure is 1/500 sec at f/8, for 1500 m altitude. A 35 mm camera is also used, a Nikon F2 with a 50 mm f/3.5 lens. The light meter on the Nikon is used in conjunction with an aerial exposure computer to set the correct exposure on the Hasselblad.

FIELD CAPABILITY

Deployment and retrieval of dye buoys requires a water surface capability consisting of boats, crews, buoys, and accessory equipment. A 16-ft. Thunderbird is normally employed. During the current year there was considerable development of this surface capability, especially of the dye buoys. A critical success for future work is the design and testing of an inexpensive (about $7.00) disposable biodegradable window-shade drogue (described below) which measures currents at depth and emits dye for several hours. Hundreds of these drogues will be required for large-area studies. For the small-area studies this year, surface dye buoys were used. All the buoys are described in Chapter 2 of Part Three.

COMMUNICATIONS

Air-land-sea communications were established this year via 5-watt Citizens Band transceivers. On the aircraft, a small external antenna was mounted adjacent to the camera port. The CB unit in the aircraft is used with earphones and powered by a motorcycle battery. On the boat, a detachable 2.4 m antenna is mounted and connected to a CB unit powered by internal supply. On land, the CB unit's own antenna and power supply are sufficient. The aircraft-boat link is best. When, occasionally, aircraft-land communication dies out, messages can be exchanged via the boat. The arrangement is always satisfactory for slant distances of 8 km. Recently, an additional land station was established at VIMS which can monitor mission progress at distances of 24 km.

DATA RECORDS AND STORAGE

Data forms have been adopted for use during missions. Film, camera, and exposure data are meticulously recorded. A post-mission report format is in use which standardizes the collection of narrative detail. A data library system is slowly evolving as collected data grows in volume.

Although only enough effort has been given to these details to ensure successful missions, we are fitting the details into a long-range view of an accessible photographic data library, and an Atlas of Estuarine Circulation.

DATA REDUCTION AND ANALYSIS

Film is sent by bus to Berkey Film Corporation in New York City. Other processing firms with cheaper prices are being sought.

Processed film is presently reduced with a variety of techniques. During the past one or two years many instruments at VIMS and elsewhere have been employed as part of this and other closely-related NASA contracts. The techniques and instruments include: macrodensitometry (VIMS; NASA Wallops), scanning microdensitometry (NASA Wallops), isodensity contouring (NASA Langley; U.S. Geological Survey, Reston, Va.), manual pattern tracing (VIMS), optical pattern tracing by Bausch & Lomb ZT-4 transfer scope (NASA Langley), and a comparator measurement (NASA Langley). VIMS also has a Kelsh plotter.

Data for the circulation studies conducted heretofore could often be reduced manually without much penalty in time. However, digital data output from some of the above techniques are frequently computer processed and automatically plotted. The remote sensing software capability at VIMS has grown in the past year.

2. URANINE DYE CAKE BUOYS

INTRODUCTION

To facilitate the study of nearshore circulation by remote sensing, a technique has been developed which uses dye-releasing buoys as current indicators. This section presents the evolution of techniques for construction of the buoys used in the field studies reported elsewhere in this report. The buoys provide an economical and simple method by which current data can be collected in complex tidal systems.

Uranine dye is combined with polyvinyl alcohol to form an easily handled dye cake. These cakes can be incorporated in several varieties of dye buoys, each variety suited for a specific use in estuarine remote sensing applications. Uranine dye cake buoys produce a highly visible yellowish-green plume which can be tracked by sequential aerial photography. Results have been used to ascertain nearshore circulation patterns in applications discussed elsewhere in this report.

APPLICATION

Two modes of deployment of the dye cakes have been used successfully--as fixed (anchored) markers and as integral parts of drogued buoy systems. When used in a fixed marker, the dye cake releases a bright yellowish-green stream which serves as a streak line. When used as part of a drogued Lagrangian buoy system, the dye cake produces a bright yellowish-green plume or patch,

whose shape depends on the strength of vertical shear between the water surface and the drogue depth. Data collection is accomplished by taking repetitive sequential aerial photographs of the study area once dye cakes have been deployed.

FABRICATION OF DYE CAKES

Evolution of Dye Mixture

During the early stages of development several years ago, under the direction of E.P. Ruzecki, several non-toxic dyes of the Rhodamine family of fluorescent dyes were tested to determine visibility from an aircraft. Dyes tested were Rhodamine B, Pantacyl Brilliant Pink, and Uranine. All three dyes are soluble in water and fluoresce when excited by solar illumination. The first two, Rhodamine B and Pantacyl Brilliant Pink, produce a scarlet-colored plume which proved to be difficult to see in turbid waters, in the relatively small concentrations which are normally encountered, from an aircraft flying as low as 200 m. The third dye, Uranine (sometimes known as Sodium Fluorescein-- chemical formula $Na_2C_{20}H_{10}O_5$) produced a brilliant yellowish-green plume which was easily visible from altitudes of 3,000 m. Plumes of all three types of dye were photographed using color, color infrared, panchromatic, and panchromatic infrared film. The best results were obtained from Uranine dye photographed with color film.

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Development of Fabrication Recipes

Uranine powder is commercially available from Allied Chemical Company in various packages, from one pound (453 gm) jars to 100 pound lots. (All components and sources are listed in Table 9.) The dye is a highly hygroscopic orange-yellow fine powder and is difficult to transfer and handle without making a magnificent yellow mess. We have developed a method for handling this dye. The development evolved through several phases.

1) A mixture of dye powder, gelatin, and hot water, sufficiently concentrated to congeal, would not dissolve quickly enough to produce a visible plume.

2) A slurry of dye powder in alcohol was made. The plan was to place the mixture in a porous container (i.e. a paper tube) and allow the alcohol to evaporate. Alcohol evaporated slowly (even when aided by elevated temperatures) and the resulting dye cake crumbled.

3) At the suggestion of Robert Long of NASA Wallops Flight Center, the dye was mixed with 10% (by weight) polyvinyl alcohol (PVA) powder and compressed to form cakes. The cakes held together for approximately one week, developed cracks and crumbled.

4) The successful method for dye cake fabrication was discovered by E.P. Ruzecki through what might be called "an experiment in desperation." A small amount of hot coffee was added to some of the Uranine-PVA mixture. The mixture dissolved, assumed a thick plastic consistency and hardened to a cake form in approximately five minutes. The reaction of the dye-PVA mixture with the

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TABLE 9.   SOURCES OF MATERIALS FOR DYE BUOYS

Material	Source	Cost
Uranine (Sodium Fluorescein)	Allied Chemical Company Specialty Chemicals Division P.O. Box 419 Hawthorne, New Jersey 07507	$375/100 lb. lot
Polyvinyl alcohol (Gelvatol type 20-30)	Monsanto Chemical Company 320 Interstate North Parkway Atlanta, Georgia 33039 Attn: Robert Bilton	$0.72/lb.
Muslin & Cheesecloth	So-Fro Fabrics 14-468 227 Newmarket North Newport News, Virginia 23605	3 yds/$1.00
Fabric Adhesive	Sears, Roebuck & Co. Sears Craftsman Stitchless Mender Fabric Adhesive 98070 (tube)	
Seining Twine	Sears, Roebuck & Co.	
Iron reinforcing rod	(construction industry)	

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hot coffee was exothermic. The chemistry of this method has not been investigated. For production cakes, hot water has been substituted for the coffee with no noticeable alteration of results.

Casting Methods and Equipment

To form solid dye cakes which are easily handled in field operations, the following procedure is used:

1) Mix (by weight) 10 parts Uranine powder (Sodium Fluorescein) with 1 part polyvinyl alcohol (PVA). PVS is a coarse white powder available from the Monsanto Company under the trade name Gelvatol - type 20-30. The PVA must be thoroughly mixed with the Uranine powder.

2) In a gallon size metal container, combine, by volume, 8 parts of the dye mixture with 1 to 1½ parts hot water (temperature approximately 90-95°C). Add the water slowly while stirring the dye mixture. The color of the mixture will change from a deep red (volume reflection) to a dark, metallic green (surface reflection). Care must be taken to ensure that no clumps of dye powder adhere to the sides of the mixing vessel. The quantity of hot water added is critical. Too much water will produce a mixture that will not solidify. Too little water will cause the mixture to solidify before it can be transferred to a casting vessel. Proper consistency of the water-dye mixture is reached when a viscosity is reached of approximately 1000 Poise (1000 gm/cm-sec) (i.e. the consistency of pancake batter, pure thick

honey, or three finger poi). The reaction is exothermic; hence caution should be used in handling the mixing vessel.

3) When the dye mixture is completely dissolved and of the proper consistency, it is poured into casting vessels. For this study, casting vessels were 8 ounce paper hot/cold drinking cups and 8 ounce styrofoam drinking cups. Paper cups are preferred because they are biodegradable. Casting should be sufficiently rapid to produce streams (between mixing and casting vessels) of more than 0.5 cm diameter. Streams smaller than 0.5 cm diameter have a tendency to solidify during the pouring process. Once cast, dye cakes should be allowed to solidify for 24 hours.

Yield of Mixture

The combination of 8 parts dye-PVA powder mixture with 1 part hot water will yield 4 parts of dye cake, a reduction of dye volume to one-half the original. Hence, if an eight ounce measuring cup is used, 8 cups dye powder + 1 cup hot water yields 4 eight ounce cups of dye cake. One pound of Uranine powder has a volume equivalent to approximately 3 eight ounce cups; thus, each one-pound jar of Uranine will produce 1.5 eight ounce dye cakes using the above formula.

Environmental Considerations

1) Fabrication Work Area

The mixing and casting of dye cakes will result in distribution of the finely divided Uranine powder throughout the work area unless extreme care is used while transferring and mixing the dye.

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High relative humidity in the work area can result in "bleeding" of the finished dye cakes, and undesirable caking of exposed Uranine powder because of the hygroscopic nature of the dye.

Temperatures in the work area should be kept above 10°C (50°F). Lower temperatures will result in premature hardening of the dye-hot water mixture in the mixing vessel. If casting must be done at lower temperatures, premature hardening can be alleviated by placing the mixing vessel on a hot plate while in use.

2) Field Study Area

Water temperatures in the study area affect the rate of dissolution of the cakes. An eight ounce dye cake made with 10% PVA will produce a visible plume for six hours if ambient water temperatures are greater than 10-15°C (50°-60°F). Lower water temperatures result in a slower dissolution rate with a corresponding weaker plume. This problem can be remedied by reducing the quantity of PVA in the casting mixture to 5%. Field tests show that the reduction of PVA results in more rapid dissolution, and a shorter lifetime during which the dye cake produces a visible plume. The lifetime may be increased by increasing the size of the dye cake.

BUOYED DYE CAKES

The initial use of dye cakes, by E.P. Ruzecki several years ago, was as fixed position markers, that is, stationary buoys

producing a dye stream along the current direction. Components were designed to withstand impact resulting from being dropped from an aircraft flying at 100 knots at an altitude of 30 to 60 m. This early design buoy "system" is shown in Figure 22 and consists of an anchor, a dye cake buoy and a connecting line. The anchor was a common brick. The brick was placed in a plastic bag as a container in case the brick shattered on impact. The dye cake buoy consisted of a section of 2 inch (5 cm) diameter plastic pipe with a series of ½ inch (12 mm) holes drilled at 2 inch (5 cm) intervals, and foam plastic end-caps. Cake construction was accomplished by taping the ½ inch (12 mm) holes, inserting one end cap and filling the plastic pipe with liquified dye mixture (10% PVA). When the dye solidified, the second end-cap was inserted, the tape was removed from the holes, and the anchor line was attached and wound around the cake.

Studies under this grant have employed newer designs of both fixed and free drifting dye cakes (streamers and floaters, respectively). As a result of this dual use and the desire to use cheap and biodegradable components, dye cakes are currently fabricated for both uses into eight ounce paper cups.

Fixed Buoys

A buoy anchored to the bottom and equipped with dye cakes is used to distinguish direction of flow through time from a fixed point, and to provide a fixed point of reference from which to deploy and track free floating dye cakes. As the fixed buoys
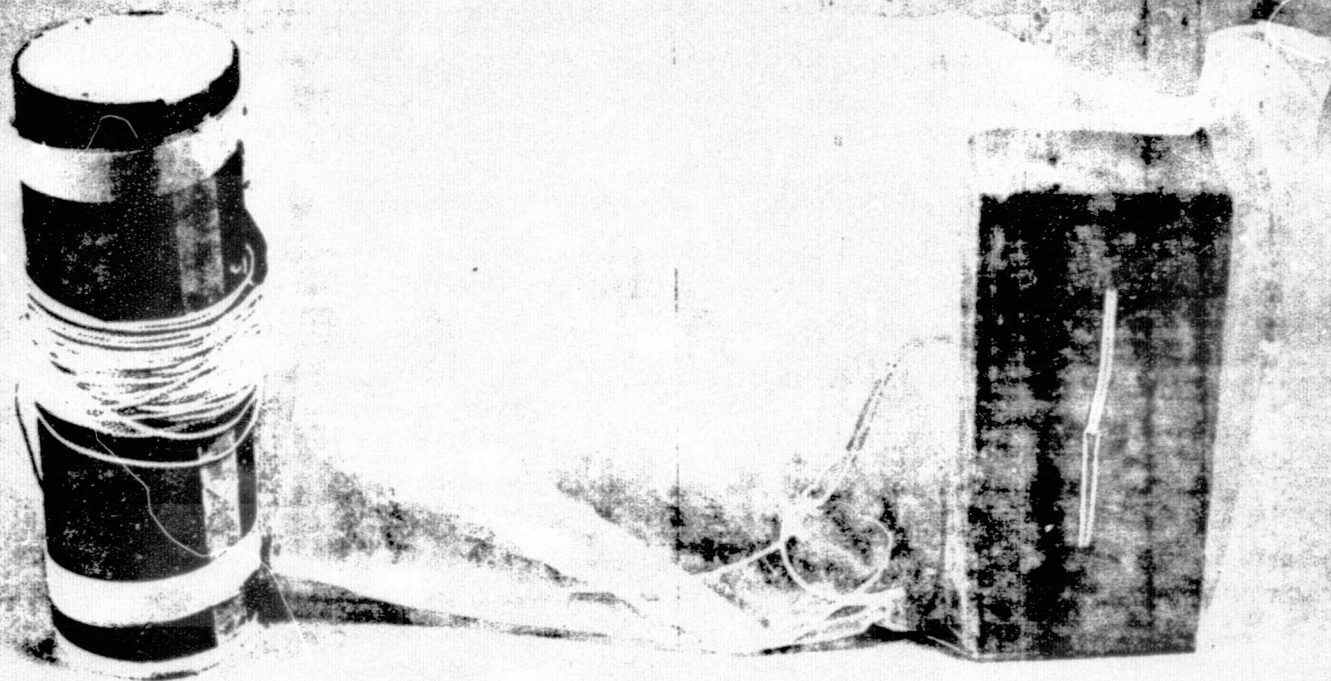
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Figure 22. Early design of assembled uranine dye cake with brick anchor.

are normally required to produce a well defined dye plume for a
long period of time (up to 6 hours in tidal cycle studies), they
are constructed with 3 eight ounce cups of dye per buoy. Fewer
cups are needed in weak current. These cups are stuffed into the
toe of a nylon stocking. A 6 inch (15 cm) diameter spherical
plastic float is added to the stocking. The stocking is then
knotted with both ends of a tie rope from the float protruding
from the knot in equal lengths. One end of the tie rope is tied
around the first cup at the toe of the stocking forming a horse-
shoe. With the small float inside the stocking, this keeps all
three dye cakes near the water surface and produces a well defined
dye plume. The other end of the rope is attached to a 12 inch
(30 cm) diameter plastic float. This large float is required to
keep the dye cakes at the surface in areas of strong current.
It provides a visible marker for boat traffic, and is detectable
in aerial photographs. The float is then anchored with a brick
anchor. Figure 23 (top) shows the completed "streamer". Figure
24 shows it in field operation under strong current conditions.

Floater Buoys

A free floating buoy has been developed for the purpose
of measuring current velocity as a function of time. The basic
floater consists of one dye cake, a flotation device and a wrap-
ping to hold the two together. The earliest design consisted of
a dye cake cast in a styrofoam cup and a 6 inch (15 cm) diameter
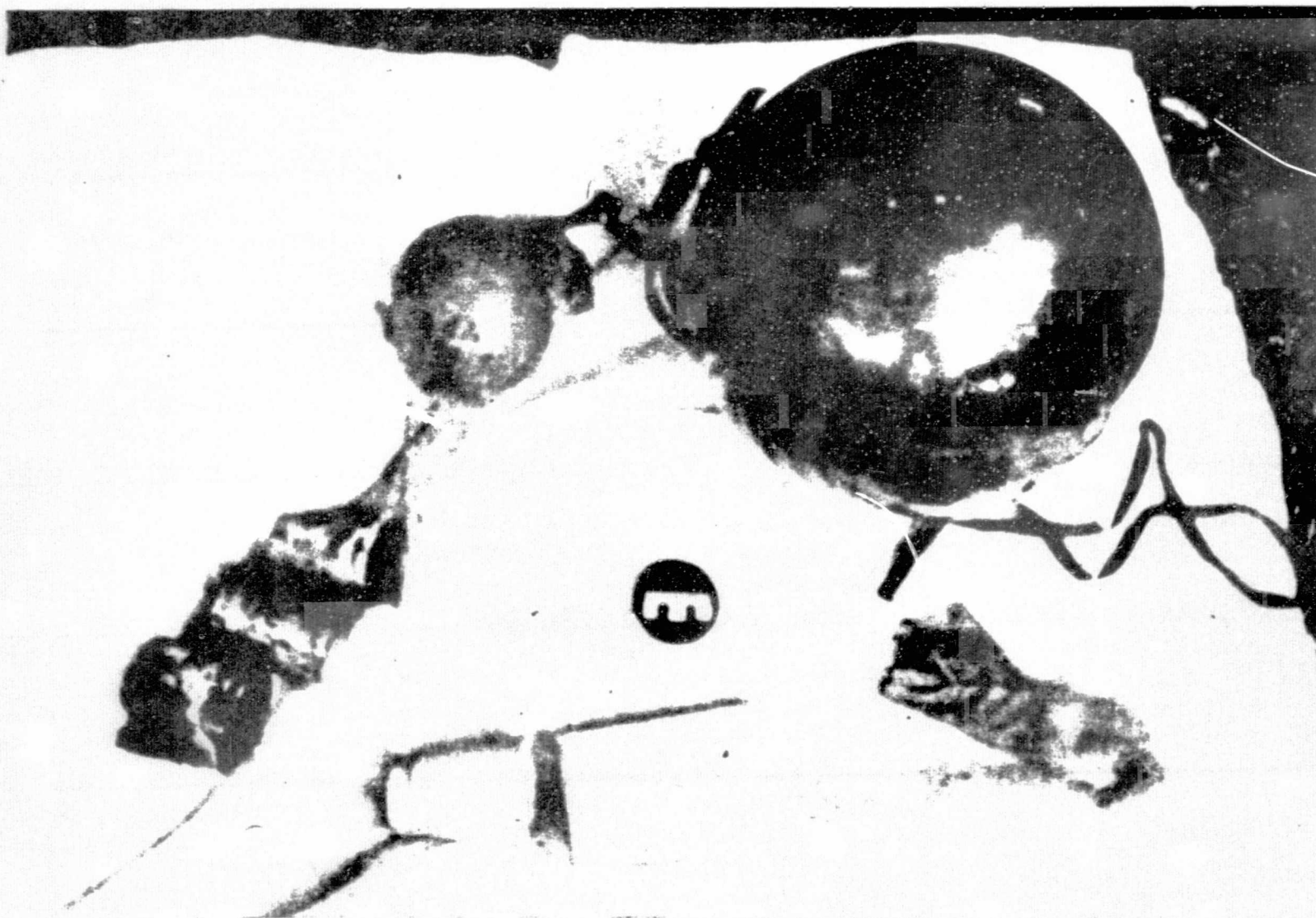plastic float. The float and dye cup were placed close together

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Figure 23. Uranine dye cake buoys. Top: Fixed position
marker which emits a dye stream following the
local current vector; brick anchor not shown.
Bottom: Floating dye marker for tracking water
mass movement.

Figure 24. Fixed-position dye cake buoy in field use.

at the toe of a stocking to release dye close to the water surface. The design resulted in a buoy with low windage and little difficulty in deployment. However, when large numbers of floaters were used during a study, there was difficulty in recovering all the floaters.

To make a biodegradable floater buoy that was economical and expendable, several substitutions were made in the materials. Hot/cold paper cups were substituted for the styrofoam cups, and the plastic floats were replaced with 6 inch (15 cm) sections of nominal 2 x 4 inch wood (5 x 10 cm). These were combined in a nylon stocking as in Figure 23, bottom. The use of a wood block lowered the wind resistance surface while maintaining buoyancy.

A further modification was to replace the stocking with a cheese cloth bag. The cheese cloth was attached to the wood by rolling the edges into a thick layer and stapling it with heavy duty staples to the edges of the wood. First one side was attached, then the dye cake was put under the wood and the other side rolled and tightened around the dye cup and fastened to the wood. The two end pieces were then drawn up and folded at the ends of this wood float, and stapled. This arrangement forms a completely biodegradable and economically expendable floater package. Placing the dye cake directly below the float ensures that the dye cake will remain near the surface. The floaters were numbered with paint for identification when large numbers were deployed.

Window Shade Drogue Buoy

A new window shade drogue has been designed which incorporates a dye capability. The function of the drogue is to follow subsurface current flow and leave a dye plume on the water surface that can be remotely sensed. These buoys cost about $7.00 and are biodegradable (Figure 25). The construction of the drogued buoy is in two parts. The drogue itself is constructed of unbleached muslin in the shape of a window shade which orients itself perpendicular to the direction of the relative current. The top is glued with a fabric adhesive and stapled with heavy duty staples to a piece of nominal 1 x 2 inch (2.5 x 5 cm) wood. The bottom of the fabric is glued to a length of 0.5 inch (12 mm) diameter iron reinforcing rod. The wood acts as a float and the rod acts as a weight to produce a negatively buoyant float that will keep the muslin sheet extended. The length of the reinforcing rod determines the buoyancy of the drogue.

The second part of the buoy is the surface dye-chamber float, constructed from a 6 inch (16 cm) length of nominal 4 x 4 inch (10 x 10 cm) square post stock with the corners removed to form an octagon. A 2 inch (5 cm) diameter hole is drilled out of the top of each block to a depth of 4 inches (10 cm) forming a chamber for the dye. Four holes of 0.75 inch (2 cm) diameter are drilled on the sides of the block at the base of the chamber forming an outlet for the dye. A screw eye is centered in the bottom of the block. Using the technique described earlier, the dye is mixed, the side holes are taped and the dye is poured into the chamber and allowed
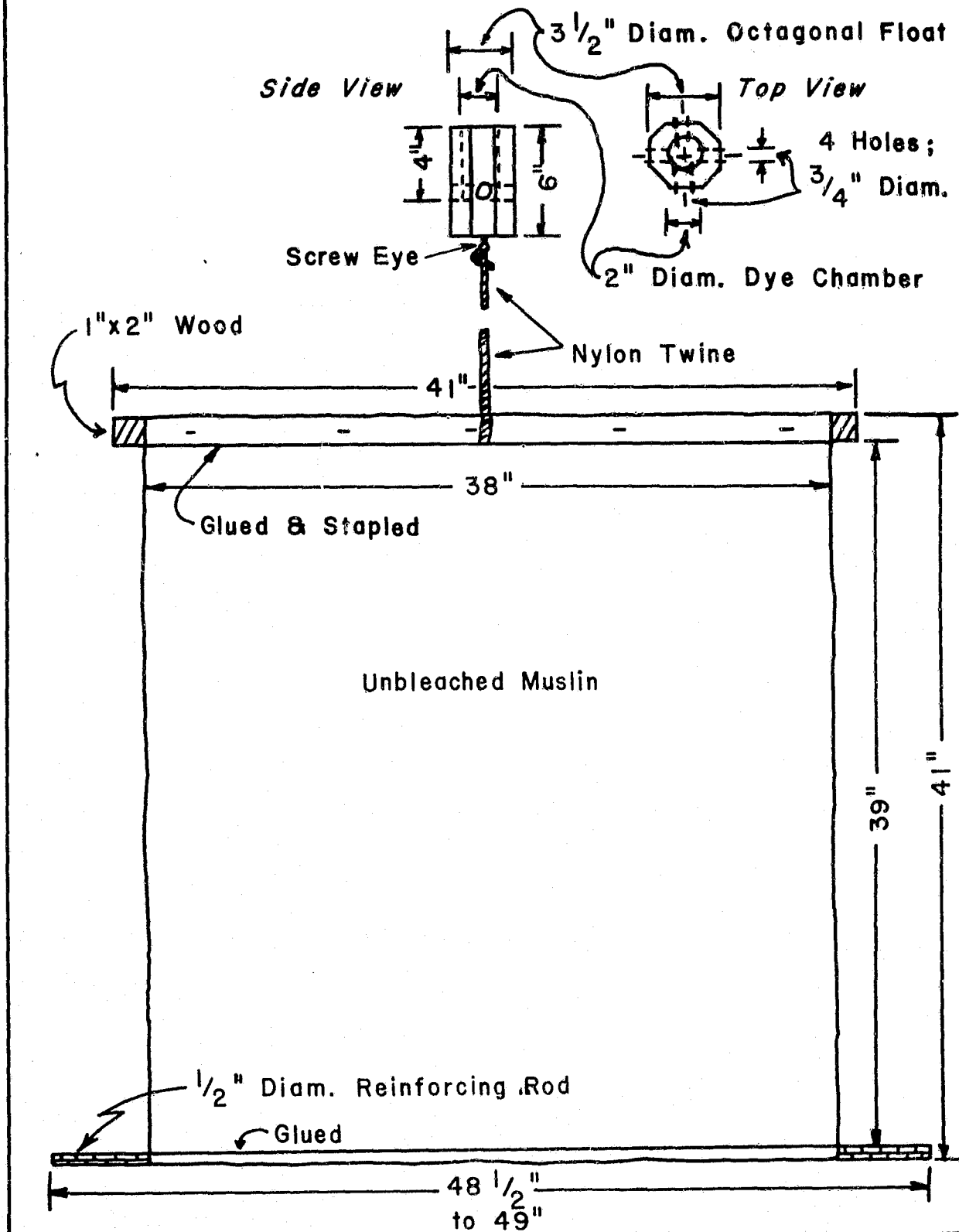
Figure 25. Design of dye-emitting window-shade drogue. Depth of current-following window-shade is set by length of the nylon twine.

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to set. The top of the chamber is then sealed with tape. Just before deployment, the tape is removed from the side holes.

The dye chamber float is attached to the drogue by seining twine in the length desired to position the drogue at the depth of measurement. The dye chamber floats with only 2 to 5 cm of freeboard to reduce wind drag.

Field Operation

The typical field operation requires a boat and an aircraft equipped with a vertically mounted camera. Radio communication between the boat and aircraft is essential to a successful study. Minimum personnel required for this type of study include a pilot and cameraman in the aircraft, and a helmsman and mate in the boat to deploy and recover the dye buoys.

Fixed buoys are usually deployed first as marker positions for initial drop points for the floater buoys. They are also useful as indicators of current direction. After radio communication has been established between the aircraft and the boat the first set of floater buoys is deployed. This can be done quickly by steering a course past all the drop points and, without stopping, throwing out a floater at each desired position. The floater buoys will immediately orient themselves and begin producing a dye plume. The drogued buoys described can be deployed quickly after the tape has been removed from the dye chamber. The windowshade will automatically unroll when it hits the water.

After the deployment of the buoys, the aircraft takes a first series of photographs of the buoy positions and the study

site. At a later interval, determined by the circulation charac-
teristics of each study site, a second series of photographs is
obtained. Depending on the study requirements, additional buoy
deployments may be required. As the number of buoys increases,
identifying the floater buoys on the aerial photography can become
difficult. A technique for positive identification has been de-
veloped during this year's work by which the aircraft searches for
the visible dye plumes and directs the boat to the buoy by radio.
The boat personnel can then identify the number painted on the
buoy and relay this information to the aircraft, where the relative
position and number of the buoy is plotted on a chart with the time
of observation. This information is later used to identify in-
dividual buoys in the aerial photographs. The alternative would
be photography frequent enough to keep track of all buoys individu-
ally without boat-assisted identification.

This dye buoy technique has been used in various appli-
cations of nearshore circulation and is amenable to other uses.
Similar techniques have been reported by Welsh (1967), and Yeske
et al. (1975). Yeske and co-workers developed a thorough photo-
grammetric data reduction procedure for offshore photography of
large numbers of buoys.

CONCLUSIONS

The conjunction of dye buoys and remote sensing techniques
has proved to be an economical and easy method to study nearshore
tidal circulation. The approximate cost of each dye cake is $5.00,

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which allows for the deployment of large numbers of current indicators at a relatively low cost as compared with current meter operations. Construction of the dye cakes and the various buoys is easy and rapid. Little initial cost outlay is required for raw materials for both the dye cake preparation and buoy construction. The buoys are biodegradable as well as economically expendable. Field deployment of the highly portable dye buoys is a relatively simple procedure. To date, results of studies in a wide variety of nearshore circulation applications indicate the method is both economical and practical.

3. OMEGA BUOY SYSTEM DEVELOPMENT

INTRODUCTION

A remote circulation analysis system using free drifting buoys and the Omega Navigation System was proven feasible this year. The concept, presented in the annual report for last year (Zeigler et al., 1974), is briefly reviewed below. During the current year, a test buoy has been built and successfully deployed, demonstrating all the phases of the concept except time sharing of the navigation among several remote buoys. This report includes the engineering description of the buoy system in its current realization, and a discussion of the results of experiments to date.

Omega buoy system development will no longer be supported under this grant. A proposal for further support has already been submitted elsewhere.
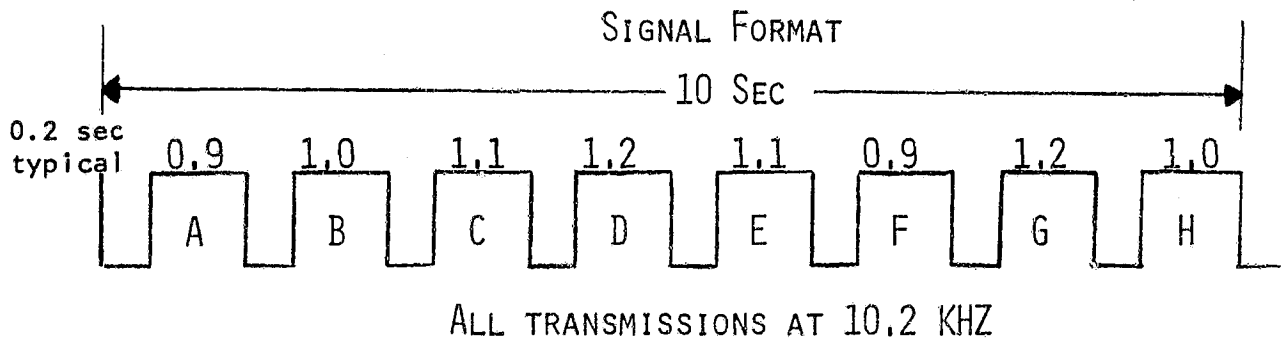
USE OF THE OMEGA SYSTEM FOR BUOY TRACKING

The Omega Navigation System was developed by the Navy in order to provide worldwide positioning information to its ships. The network is serviced by a total of eight stations throughout the world: Norway, Trinidad, Hawaii, North Dakota, Reunion, Argentina, Japan and Australia. The first four were operational in August of 1974. They broadcast at a frequency of 10.2 kHz in the format shown schematically in Figure 26.

OMEGA

WORLD WIDE NAVIGATION SYSTEM OF 8 STATIONS. WE WILL USE FOUR STATIONS.

        A. NORWAY

        B. TRINIDAD

        C. HAWAII

        D. NORTH DAKOTA

SIGNAL FORMAT

— 10 SEC —

0.2 sec typical

0.9 1.0 1.1 1.2 1.1 0.9 1.2 1.0

A B C D E F G H

ALL TRANSMISSIONS AT 10.2 KHZ

LINES OF POSITION, LOPs, ARE DEVELOPED FROM PHASE DIFFERENCES BETWEEN STATIONS.

BASIC SYSTEM ACCURACY OF 1 - 5.5 km.

DIFFERENTIAL MODE ACCURACY OF 0.15 - 1 km.

LARGE VARIATIONS IN SIGNAL RECEPTION DUE TO DIURNAL SHIFTS OF IONOSPHERE AND OTHER ATMOSPHERIC NOISE.

Figure 26. Omega Navigation System signal format.

Worldwide coverage is achieved due to the extremely long distance propagation of radio waves at 10.2 kHz. Stations are identified by noting the pattern of transmissions. One of the advantages of the system is that the electronics to derive the necessary position information are relatively simple, while still fully automatic.

Each pair of stations yields a family of curves of equal phase difference called lines of position (LOPs). Two LOPs (three stations) are required for a fix.

The advertised accuracy of fixes in the Omega System is three nautical miles (5.5 km). This fairly large error is due to the many factors affecting the transmission paths of the signals. The primary factors are regular diurnal shifts of the ionosphere and random atmospheric noise due, for instance, to thunderstorms and sunspots. The diurnal shift is fairly predictable, and correction tables have been published that account for much of this error source. The others are entirely unpredictable and in severe cases can cause total data drop out.

A "differential" mode of operation of the system eliminates much of the local error due to these sources. In this mode the LOPs of a fixed location are determined from signal receptions and from actual LOPs plotted on a chart. The two are compared and a differential error calculated which can be applied to other data taken in the same locale. A reasonable assumption is made here that the errors within a 50 km range are approximately the

same at the same point in time. An accuracy of 800 m has been obtained by utilizing this differential mode in our system.

Areas where good reception has been noted include the Eastern Shore of Virginia, Hampton, NASA/Langley Research Center, and Hampton Roads. Reception has been good enough to justify the utilization of Omega in our system.

VIMS itself has proved to be a poor location for Omega reception due to much power line noise and the Coleman Bridge, which shorts much of the signal to ground. This problem is local and moving a few hundred meters up or down the York River is expected to improve matters.

Our approach has been to build a cheap, simple buoy and electronics package that will receive the Omega signals and retransmit them via a 2398 kHz telemetry link to a base station. There they are reconstructed and input to a commercial Omega processor for determination of buoy LOPs. To achieve "differential Omega" the base station LOPs are also determined. All of this information is input to a Data General 1220 mini computer for storage, correction and averaging.

As discussed in detail later in this chapter, twenty-four hour data records from operational test platforms in most recent tests show that location can be determined to an accuracy of 200 m. In practice, an accuracy of 800 m is expected.

OMEGA BUOY ELECTRONICS

Circuit Summary

Omega signals are received underwater by electrodes on a weighted cable, placed at different depths. The receiver electronics amplify and filter 10.2 kHz Omega signals, and limit the signals by clipping to reduce atmospheric noise and to equalize signals from separate Omega stations. A crystal controlled 2398 kHz carrier is modulated by the clipped output of the receiver. A two-crystal filter removes the lower sideband and harmonic components of the modulated carrier. The modulation is adjusted to give equal amplitude signals at 2398 and 2408.2 kHz (the upper sideband). The carrier is retained as a phase reference for the sideband. A two-stage R.F. amplifier delivers $\sim 100\,mW_{rms}$ into a 50 ohm load. The signal is delivered to a whip antenna loaded for 2398 kHz and transmitted to the fixed land station. Figure 27 is a block diagram of the buoy circuit.

Circuit Details

The Omega buoy electronics (Figure 27) consist of a receiving antenna, an Omega antenna coupler, an Omega receiver (RCVR) that amplifies, filters and limits Omega signals, a 2398 kHz carrier oscillator and vestigial carrier modulator (MOD), an R.F. amplifier (XMTR), and an R.F. antenna coupler. The R.F. antenna is a 2.4 m loaded whip tuned to 2398 kHz.

1) Receiving antenna

The 10.2 kHz Omega signals in seawater attenuate at approximately 3.5 db/m. Signals at 2398 kHz attenuate at approximately

Omega Coupler

Receiver Box 1

3Ω

Omega Ant.
Filter/
Coupler

15
22
kΩ

Tuned
Amp.

Untuned
Amp.

Clipping
Amp.

Omega
Electrodes

Receiver Box 2

10.2 KHz Mech.
Filter
50Hz Band.

Untuned
Amp.

Clipping
Amp.

Receiver Box 3

Modulator Box

Clipping
Amp.

Modulator

2398 + 2408.2 KHz
Crystal Filter

2398 KHz
Xtal OSC

2398 KHz
Loaded
Whip
Antenna

Transmitter Box

R. F. Coupler

R.F. Amp.

100 mW_{rms}
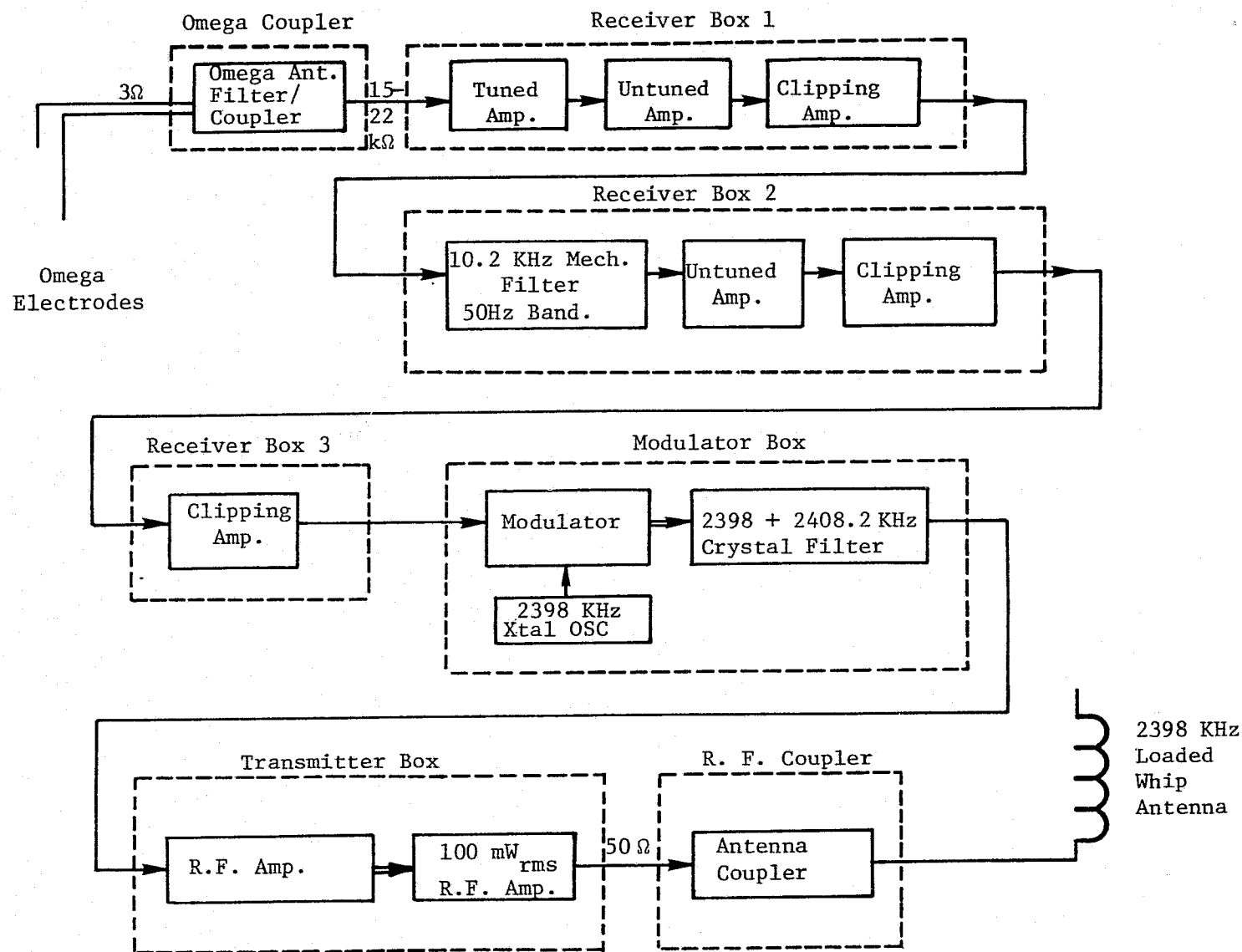R.F. Amp.

50 Ω

Antenna
Coupler

Figure 27. Block diagram of buoy electronics designed to utilize the Omega
Navigation System.

55.6 db/m. The advantage of using an underwater antenna for Omega reception is that water between the receiving antenna and the transmitting antenna acts as a low-pass R.F. filter. Assuming that seawater is an imperfect conductor at 10.2 kHz, electrodes with vertical separation are used to detect the weak currents flowing in the water as a result of the boundary conditions of the vertically polarized Omega surface wave. Observations suggest that potential differences are on the order of 0.5μVpp in the top meter of the water column. For porous copper-alloy electrodes of sufficient effective surface area, the source impedance of this meter of water is about three ohms. The impedance is not greatly affected by the separation of the electrodes if the fluid boundaries are distant by several times the electrode separation. It is more a function of electrode surface area and construction.

The electrodes are made from two halves of a porous marine radiotelephone grounding device made of sintered brass beads. They are attached to the antenna wires by brass bolts secured in vulcanized splices. The antenna cable is three-wire neoprene power cord with eyebolt terminations and vulcanized breakouts. The top electrode is at 2 m depth, with the lower electrode at 7 m. At 8 m below the surface, a 1.4 kg lead weight is shackled to the end of the cable. The ground wire is maintained unbroken through the length of the cable to provide a shielding effect. It is connected electrically to the R.F. grounding electrode on the bottom of the test boat.

2) Omega antenna coupler

The Omega coupler (Figure 28) uses miniature audio transformers to match 3.2 ohms impedance to 15 k ohms. It also has a low-pass pi-filter to reduce the pickup of 18-25 kHz signals of unknown origin. In the test boat it was found necessary to enclose the coupler in a steel utility box as well as an aluminum mini box to reduce magnetic pickup of the transmitted R.F.

3) Receiver

The receiver was built on printed circuits in three aluminum chassis boxes (Figures 29, 30, and 31). The receiver input in Box 1 consisted of two low-noise pnp transistors connected in cascade to form a tuned amplifier. The input impedance was about 20 kΩ and the Omega coupler completed the input bias circuit. The Q of the tuning was adjusted by a small resistor to keep ringing caused by atmospheric noise spikes to under one millisecond. Two 741 operational amplifiers following form a limiting amplifier, clipping atmospheric noise bursts to about ± 0.30 V. This reduces the amount of ringing in later filters.

The power supplied to the receiver circuits is ± 6Vdc. The current travels from output to input stages through successive low-pass filters made of 5 mh toroidal inductors and 50 μf capacitors. This eliminates 10.2 kHz feedback instabilities traveling through the power circuits, giving the most filtering to the input circuits.

The input to RCVR Box 2 (Figure 30) is a narrow-band (50 Hz) 10.2 kHz mechanical filter. Limiting atmospheric noise before
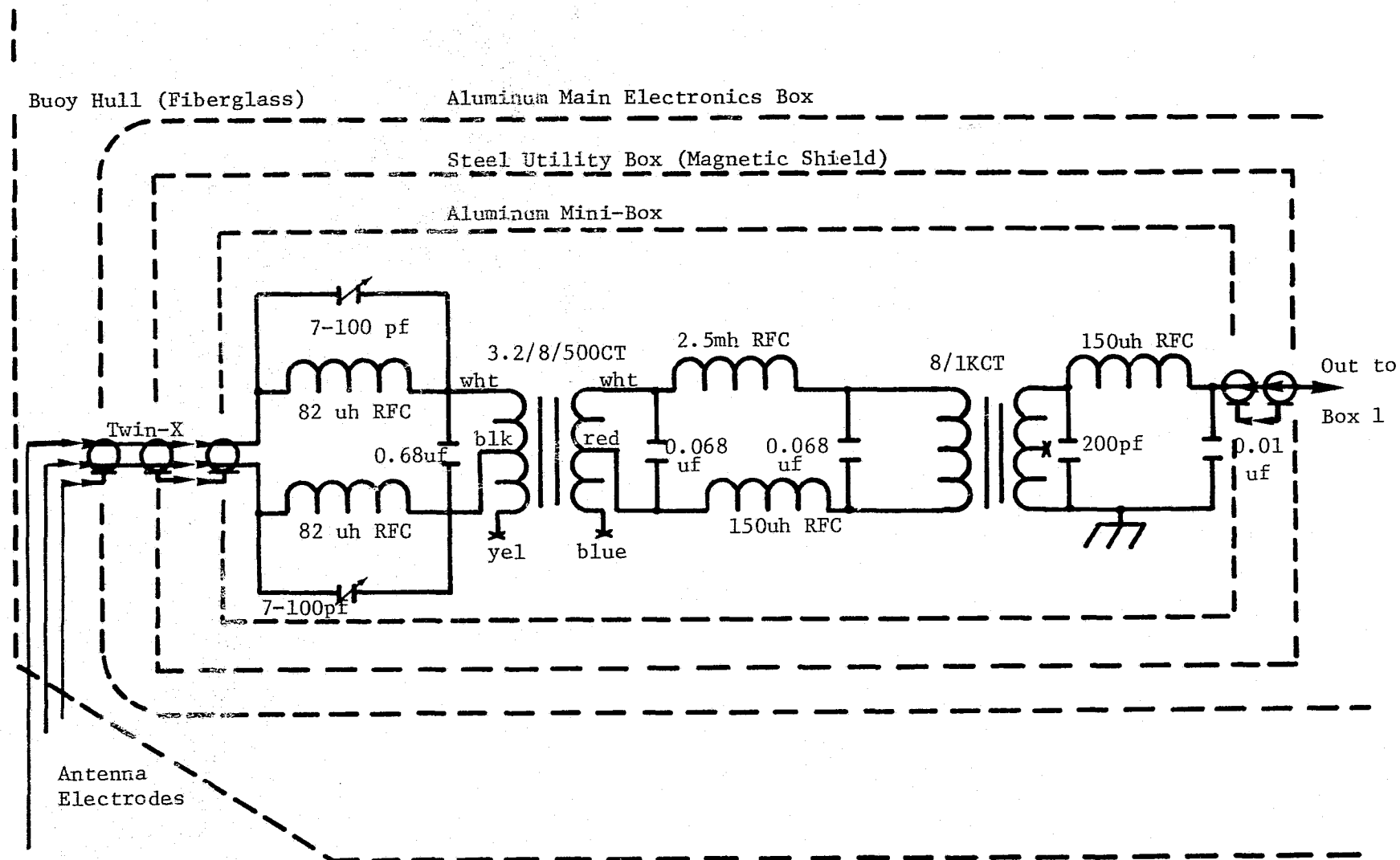
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Figure 28. Omega buoy receiving antenna and coupler circuit.

RECEIVER BOX 1
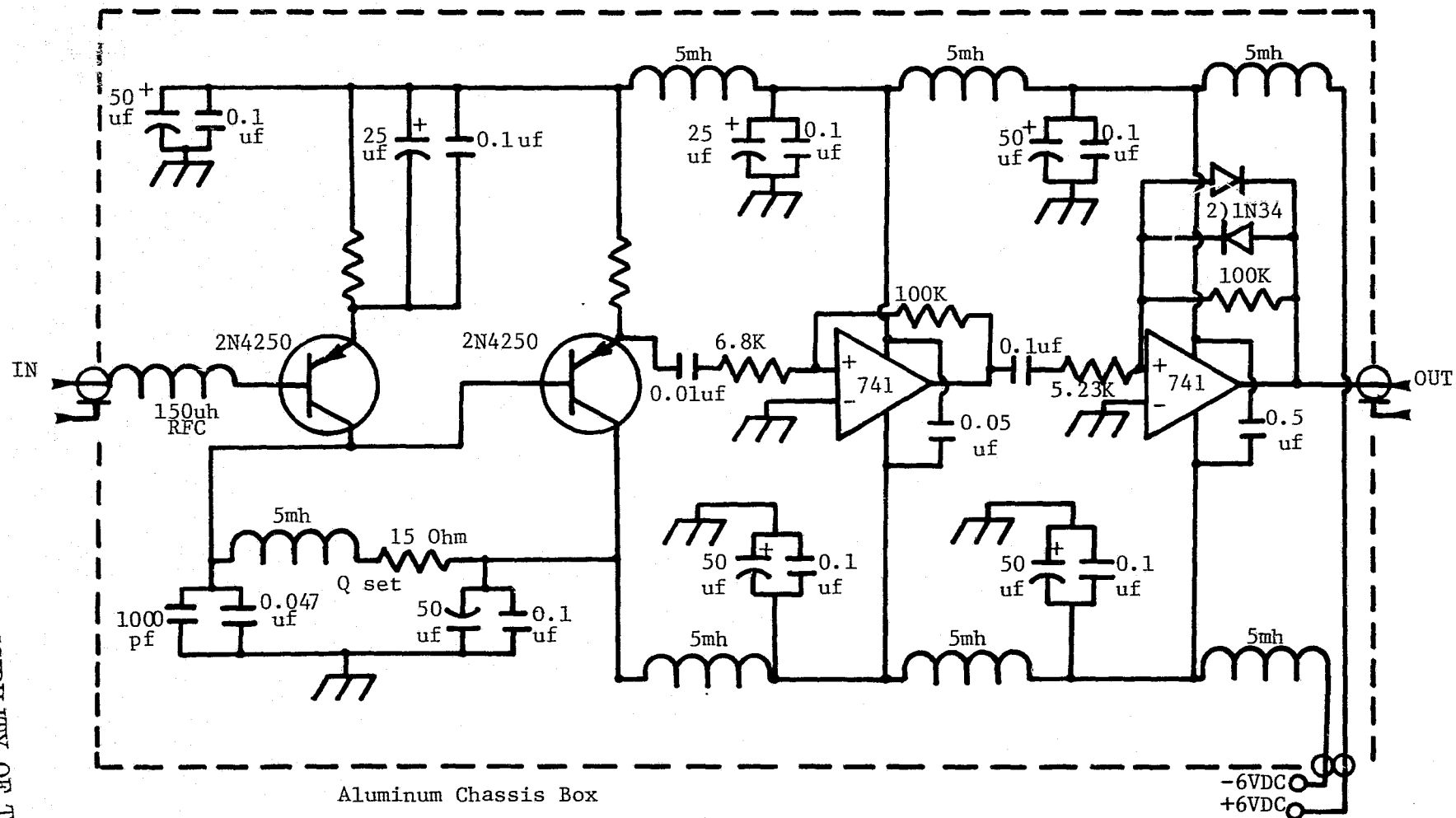

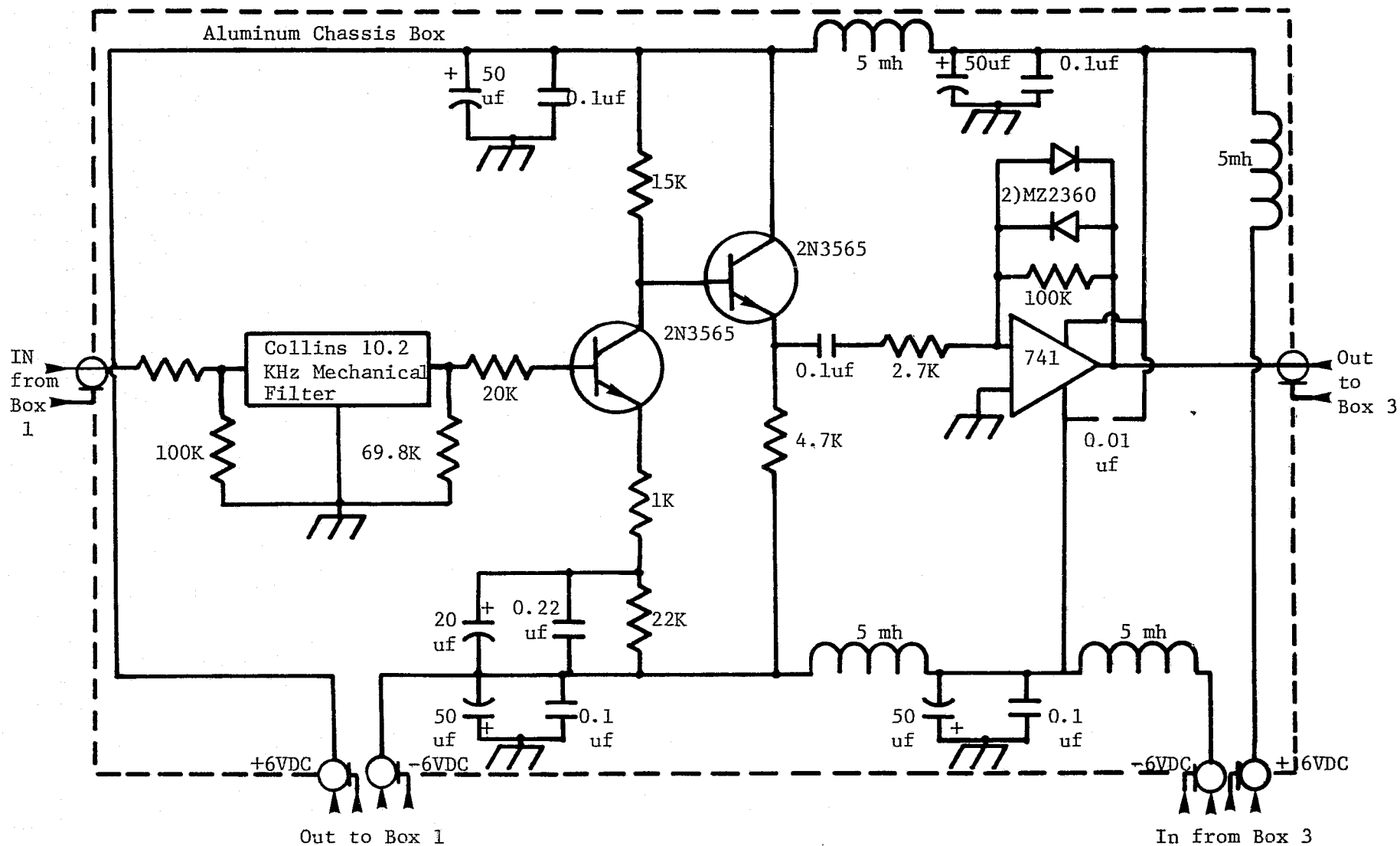Figure 29. Omega buoy receiver box 1 circuit.

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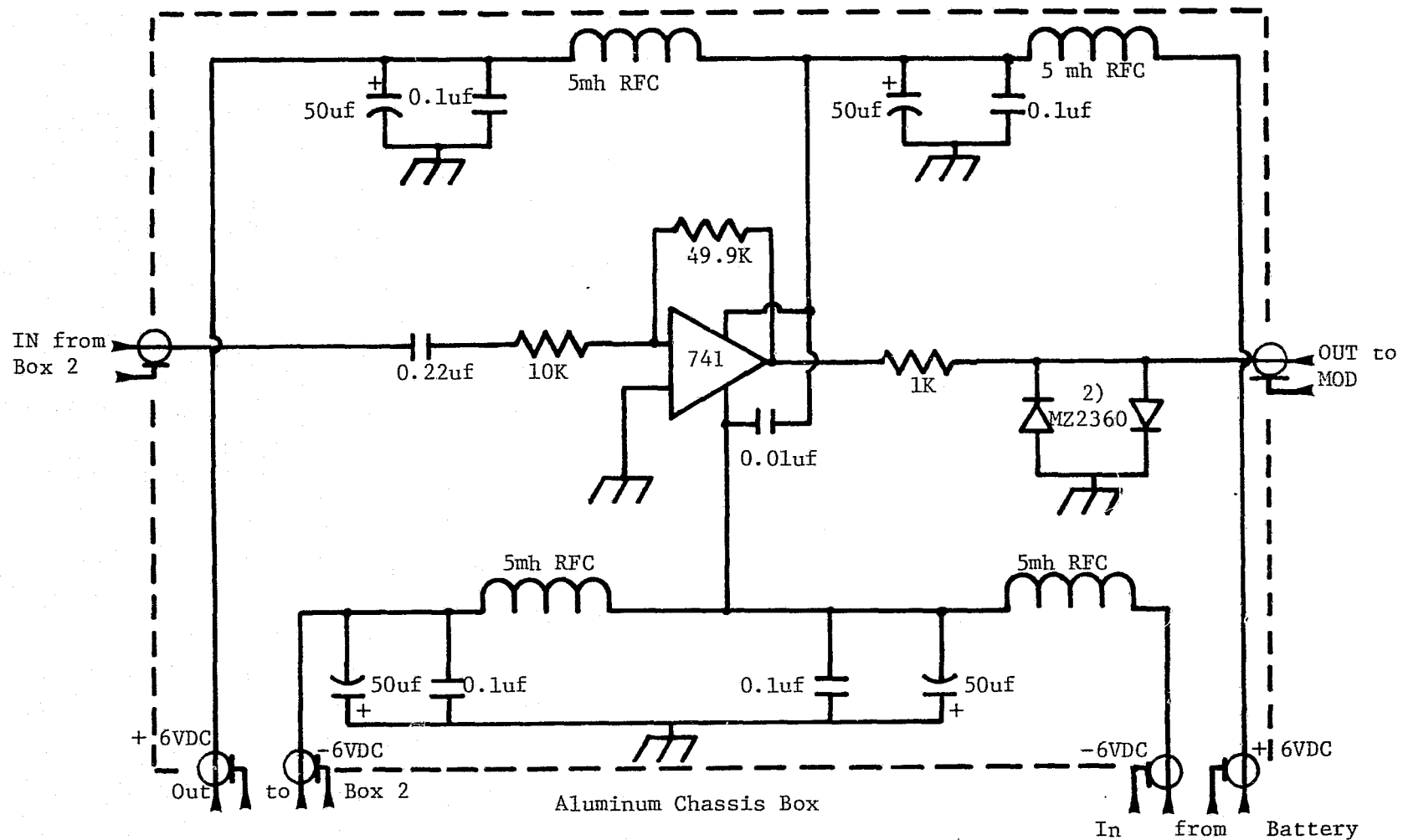Figure 30. Omega buoy receiver box 2 circuit.

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Receiver Box 3

Figure 31. Omega Buoy Receiver box 3 circuit.

this filter reduces filter ringing. The filter removes 18-25 kHz
interference and greatly improves the signal-to-noise ratio. It
is followed by a buffer amplifier and a limiting amplifier.
Another limiting amplifier follows in RCVR Box 3 (Figure 31).
The limiting amplifiers help equalize signals from different
Omega stations and establish an upper limit on modulation index.

    4) Oscillator and modulator

    The limited output of RCVR Box 3 is connected to the Omega
input of the MOD box (Figure 32). The carrier is generated in
the MOD box by a 2398 kHz crystal oscillator, and is filtered and
amplified to drive the current generator transistor in an RCA
CA3028A differential/cascade amplifier (Figure 33). The CA3028A
is operated as a mixer with single-ended Omega signal input and
differential R.F. output. The mixer output is filtered by a half-
lattice crystal filter that passes the carrier and upper sideband.
The Omega modulation drive is adjusted by a $10\,\mathrm{k}\Omega$ trimpot until the
carrier and upper sideband amplitudes are equal. The modulation
index for an amplitude modulated signal with the same sideband
levels would be 200%. The result is like a two-tone single side-
band signal and is tuned as such.

    The advantage of using equal-carrier-upper-sideband (ECUSB)
modulation is that the original carrier is available for syn-
chronous demodulation of the received signal. As long as the
delays and phase shifts in the R.F. signal, from the Omega buoy
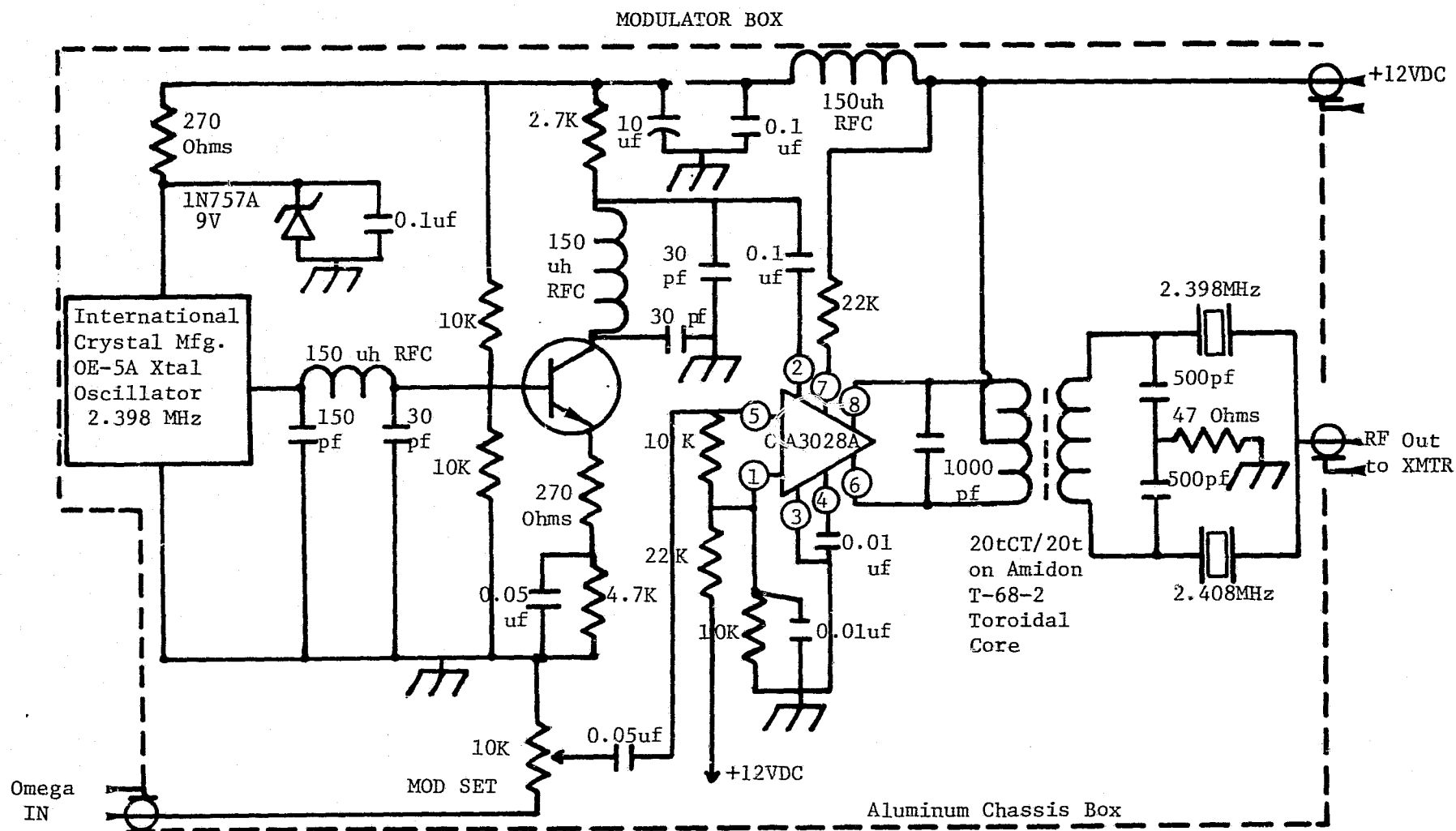modulator to the base station receiver demodulator, are equal for

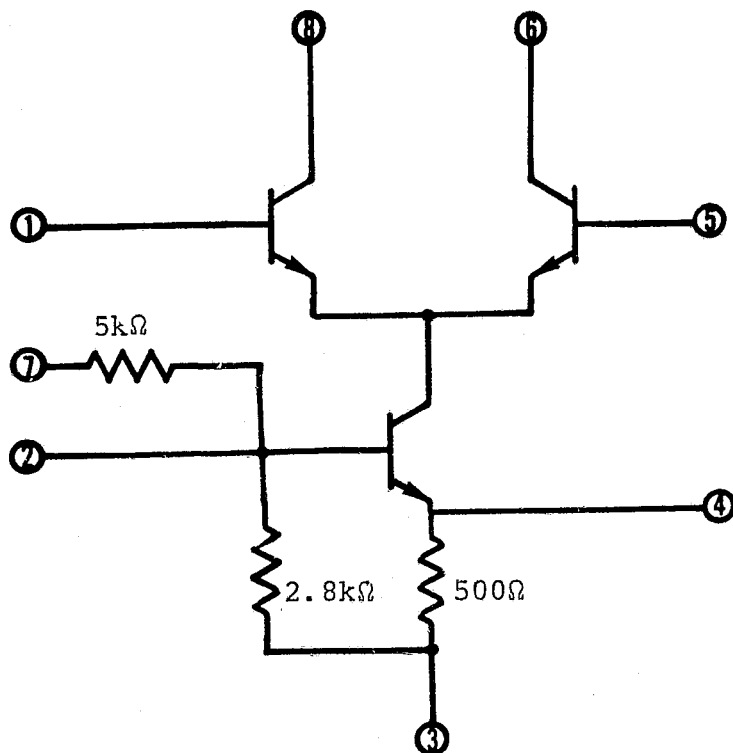Figure 32. Omega buoy modulator box circuit.

Figure 33. Omega buoy modulator box RCA CA3028A amplifier circuit.

both carrier and upper sideband, the phase integrity of the Omega signals is maintained. If the Omega signals are thought of as continuous rather than pulsed, two signals forming a line of position (LOP) can be expressed as:

$$\Omega_A = A\cos(\omega t + \phi_A) \qquad \text{and} \qquad [1]$$

$$\Omega_B = B\cos(\omega t + \phi_B), \qquad \text{where} \qquad [2]$$

$$LOP = \text{land number} + \frac{(\phi_A - \phi_B)}{2\pi} \qquad [3]$$

After the signals have been amplified, filtered, limited and used to modulate the carrier frequency, ω_c, the modulated, retransmitted Omega signals, Ω_{RA} and Ω_{RB}, are expressed as:

$$\Omega_{RA} = \cos\omega_c t + \cos(\omega_c t + \omega t + \phi_A) \qquad [4]$$

$$\Omega_{RB} = \cos\omega_c t + \cos(\omega_c t + \omega t + \phi_B) \qquad [5]$$

If the Ω_R signals suffer the same phase shift or delay, β, they may be expressed as:

$$\Omega'_{RA} = \cos(\omega_c t + \beta) + \cos(\omega_c t + \omega t + \phi_A + \beta) \qquad [6]$$

$$\Omega'_{RB} = \cos(\omega_c t + \beta) + \cos(\omega_c t + \omega t + \phi_B + \beta) \qquad [7]$$

Each Omega signal is demodulated (Ω_{DA} and Ω_{DB}) by beating the carrier component with the upper sideband component of the Ω'_R (or Ω_R) signal and filtering out the R.F.:

$$\Omega_{DA} = \cos(\omega_c t + \beta)\cos(\omega_c t + \omega t + \phi_A + \beta) - \text{R.F.} \qquad [8]$$
$$= \cos(\omega t + \phi_A),$$

$$\Omega_{DB} = \cos(\omega_c t + \beta)\cos(\omega_c t + \omega t + \phi_B + \beta) - \text{R.F.}$$
$$= \cos(\omega t + \phi_B), \qquad \text{and} \qquad [9]$$

$$\Omega_{DA} = \Omega_A, \qquad\qquad\qquad [10]$$

$$\Omega_{DB} = \Omega_B \qquad\qquad\qquad [11]$$

5) Amplifier

The ECUSB signal from the MOD is amplified for transmission by a two-stage R.F. amplifier (Figure 34). The first stage is single-ended and provides the current gain necessary to drive the second stage. Instability and distortion are reduced by emitter ballasting and collector-base feedback resistors in both stages. The first stage is resistively biased and includes a shortening diode in the collector circuit to stop collector overvoltage breakdowns. The second stage is push-pull with diode biasing. The output will adjust to a range of output impedances from 50 to 100 ohms, driving about 100 mW$_{rms}$ into 50 ohms. The XMTR is tuned by successively adjusting all three 365 pf air-variable capacitors for maximum peak-to-peak output into a dummy load. At some point the output may break down into harmonic distortion and oscillations. Either the XMTR input must be reduced, or the first two 365 pf capacitors sufficiently detuned to reduce the output to a level of stability.

6) R.F. antenna coupler

The transmitter output was assumed to be 50 Ω and an antenna coupler was constructed (Figure 35) to match it to an antenna with impedance 224-J553 ohms. The antenna coupler was tuned, with the test boat on dry land, using a 50 Ω standing-wave-radio (SWR)
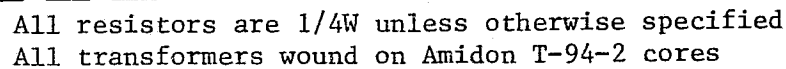
140

Figure 34. Omega buoy transmitter box circuit.
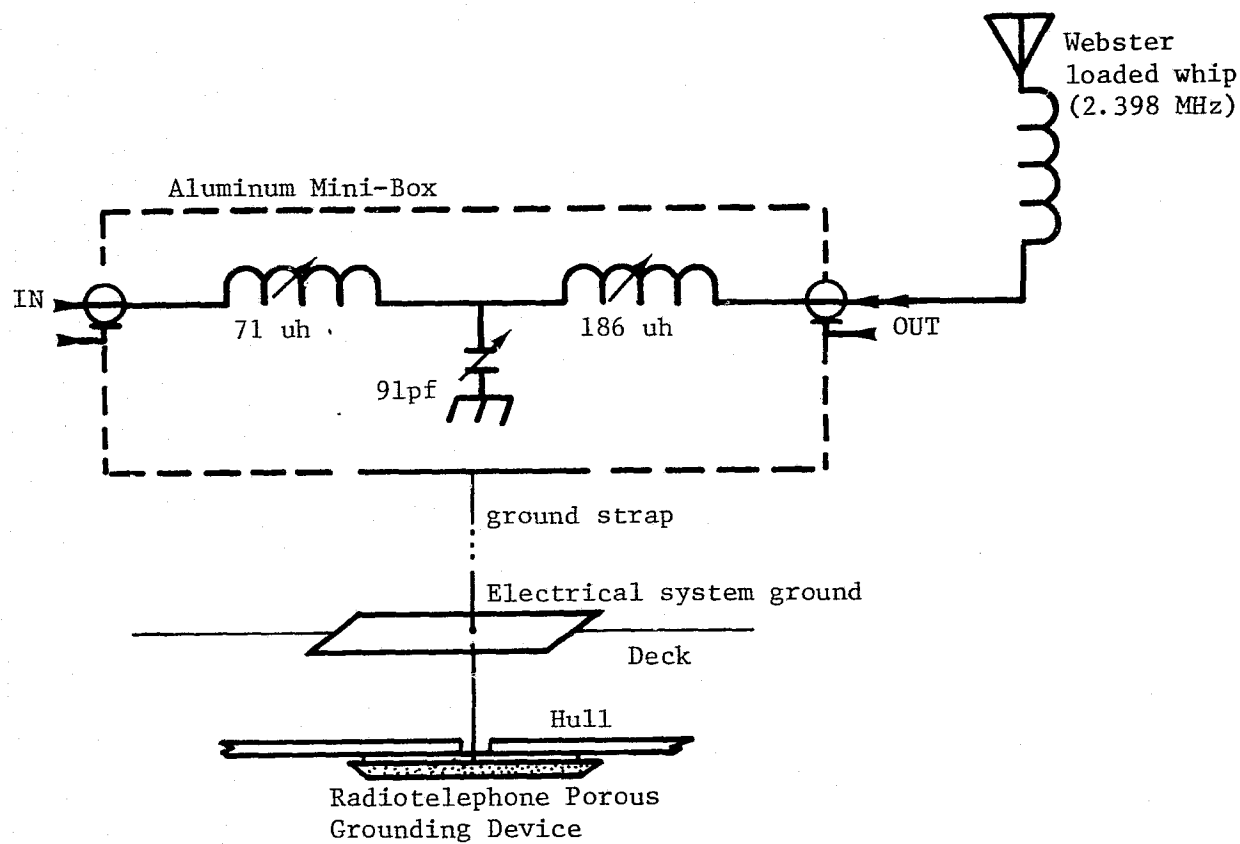
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RF Antenna and Coupler

Figure 35. Omega buoy R.F. antenna and coupler circuit.

bridge. By measuring the current and voltage and their phase relationship into the coupler, the coupler-antenna circuit was found to be dissipating about 96 mW$_{rms}$ real power. There was no means to measure radiated power.

7) Housing and power supply.

A surplus aluminum airtight case was used to house all of the buoy electronics except for the antennas, R.F. antenna coupler and lead-acid batteries. Antenna and power connections into the electronics case were made with Type-N coaxial connectors, except for the Omega antenna which used twisted, shielded pair cable and Twin-X connectors. The ±6 Vdc supply to the receiver boxes was provided by four, six-volt lantern cells inside the airtight case. The +12 Vdc and +24 Vdc supplies were provided by two 12 volt lead-acid marine batteries outside the case. The current drain from the batteries is shown in Table 10. The Omega electrode cable penetrated the hull of the test boat at the waterline and was spliced inside to twisted shielded pair cable, with the green conductor connected to the shield. All the lead-acid batteries were connected to a banana-plug patching block so that they could be recharged in parallel when not in use. The R.F. antenna coupler was mounted under the boat lid, next to the antenna base. The antenna was bolted into an aluminum block, set on top of 2.5 cm PVC plastic that was bolted to the boat lid. The ground was supplied by a porous, sintered brass bead marine radiotelephone grounding device attached to the bottom of the boat.

TABLE 10.   ELECTRONICS POWER DRAIN

Box	Supply (V)	Current (ma)	Power (W)
R.F.	+ 24	69.2 to 85	1.66 to 2.04
MOD	+ 12	16.1	0.193
RCVR	± 6	± 7.4	0.0888
		TOTAL	1.94 W to 2.32 W

Recommendations

Some problems were encountered. The worst ones were feed-back from the transmitting to the receiving section and limited transmission range. The feedback took the form of a constant oscillation at close to 10.2 kHz that at times would swamp out the signal. The cause was ground loops and electromagnetic feedback demodulated by non-linearities in the receiver. At fault was the use of many aluminum boxes and the fact that everything (except the Omega electrodes) was in the same plane above the water. The boxes provided many ground paths in addition to signal and power supply grounds. The use of a flat-bottomed boat with an interior deck precluded the use of the water as a shielding medium. By the elimination of as many ground loops as possible and by electric and magnetic shielding, the feedback was reduced to a tolerable level, allowing the Omega signals to be transmitted. The original premise of using water as shielding should have been used, by arranging the electronics in a vertical distribution in the water column, with the receiver on the bottom.

The transmission range was limited by an inadequate R.F. ground the the resulting inefficient radiation of energy from the transmitter. The same may have been true of the base station re-ceiver as well. The range of the test boat was extrapolated to be nine miles, requiring an additional 30 db of gain for a range of 100 miles. This gain might be realized by better transmitter and receiver R.F. antenna design and the addition of a 10 to 20 db

R.F. preamplifier to the base station receiver. If these measures do not produce the desired range, a higher power final R.F. stage will have to be added, with its accompanying battery drain.

Another error was the use of several different supply voltages. This required the monitoring of several sets of batteries and disproportionate battery capacities for different parts of the system. One voltage should be used for all of the circuits. Some minor corrections should include:

1) Transformer impedance matching to reduce the insertion loss of the 10.2 kHz mechanical filter.

2) A low-impedance differential input circuit to do away with the Omega antenna coupler.

3) Sharper clipping circuits with no phase shift versus amplitude for the RCVR output.

4) A high-impedance input buffering amplifier following the crystal filter in the MOD.

5) More efficient R.F. amplifier design.

BASE STATION

Brief Description of the Base Station

The base station consists of the three subsystems noted in Figure 36. They will eventually be assembled in a mobile van or hut for on-site operation.
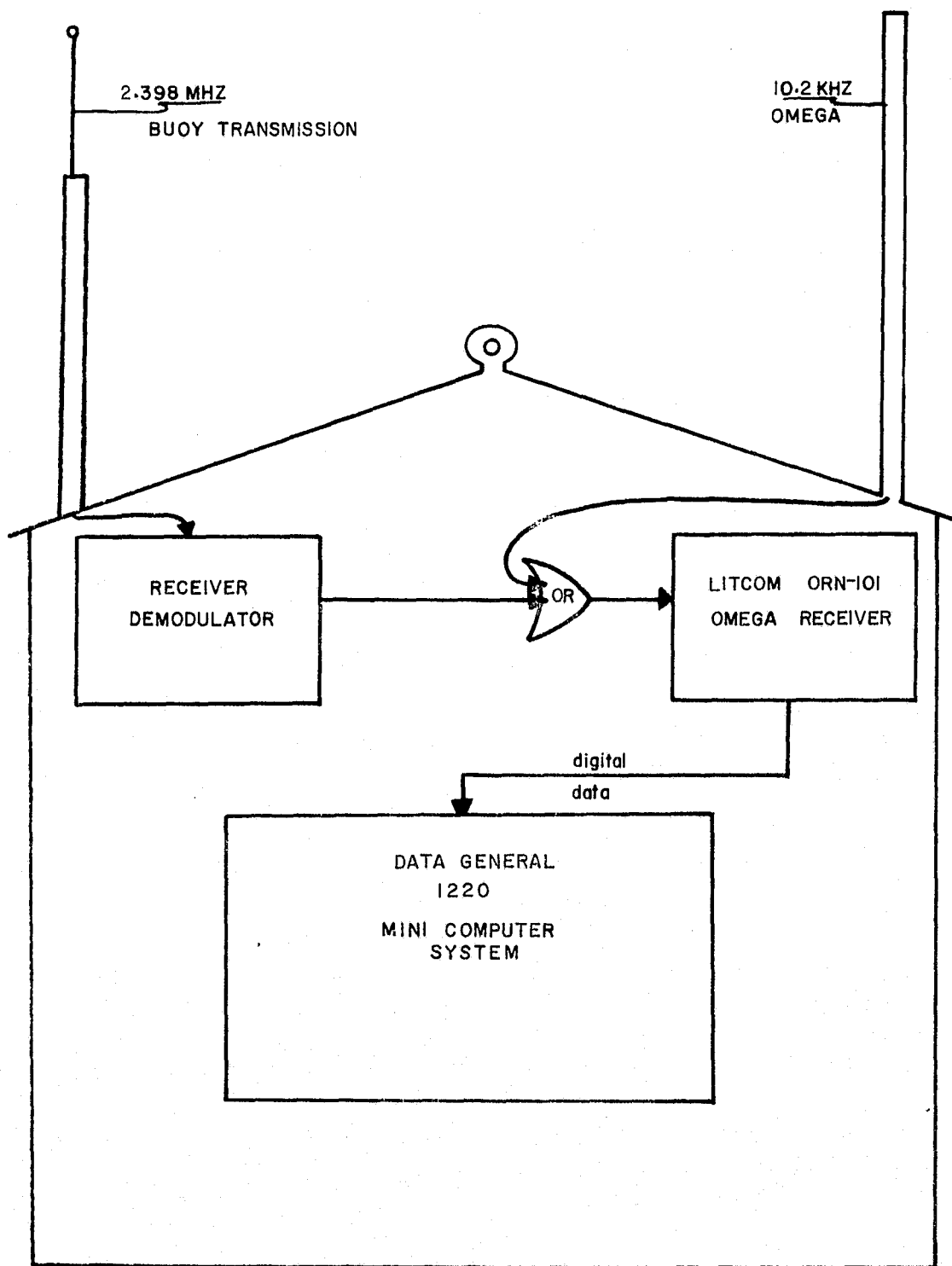
Figure 36. Omega buoy mobile base station design.

The receiver demodulator is unique in that it is required to have a 10.2 kHz bandwidth, and the demodulation technique must carefully preserve the phase relationships of the original Omega signals. These are not normally requirements in commercial receivers. It has been necessary to contract out the job of constructing this receiver to the Biological Instrumentation Systems firm in Newport News.

The LITCOM ORN-101 Omega receiver is the heart of the base station and indeed the entire system. It receives and processes signals sequentially from each buoy and in its own time slot, a signal from its own antenna.

The processor in the ORN-101 consists of a small dedicated mini computer that synchronizes on the input signals and determines the phase relationships between them. Two lines of position (LOPs) are chosen on its front panel via thumb wheel switches and these are displayed via a Nixie tube readout. Also displayed is a signal quality indication that shows when the signal to noise ratio of an incoming signal is greater than 1:10.

The ORN-101 must be switched between several signals, that from its own antenna and those from the buoys. At each switching the phase locks must be re-attained. This process, which may take several minutes, places a lower limit on sampling intervals.

As large amounts of data will need to be processed, averaged, corrected and stored, the ORN-101 was purchased with an interface to a DataGeneral 1220 mini computer. The two LOPs, time and signal quality information, are output in a binary format to the 1220.

The Data General system consists of central processor, ½ inch tape drive unit, teletypewriter and cassette tape drive unit. Programs are being developed to handle the incoming data.

OMEGA NAVIGATION EXPERIMENTAL RESULTS

The test buoy and the base station have been used in several experiments designed to develop procedures for operation and to estimate power and acquisition time requirements for an operational remote Omega buoy. Four experiments have been performed during this year, our capability being greatly expanded when the link between the receiver and the computer came into regular operation. The first experiment was a direct attempt at Omega navigation in the differential mode by directly examining instantaneous outputs of the navigation receiver. The second was the monitoring, on a round-the-clock basis, of several lines of position in order to determine the amount of noise and the pattern of diurnal variation at the VIMS base of each LOP. Some statistics were desired of the operation interruptions due to loss of transmission or poor reception for various station combinations. The third experiment was an estimate of the range obtainable from the low power system, in order to estimate power requirements for a desired range. Finally, long-term (several day) anchored buoy experiments were performed to determine system tracking and mapping of the local LOP field near the VIMS base station. The remote platform experimental work was cut short during one of these

long-term remote tracking experiments by the sinking of the test
bed during a storm. Rather than repair the test bed, our recovery
from this accident has been to start construction of a prototype
buoy using the engineering information gained from the earlier
test bed experiments.

The first set of experiments was performed in late December
1974 and January 1975 in the York River under low power. The navi-
gation was performed by positioning the test bed next to one of
the navigation markers in the York River and determining its dif-
ferential Omega position by reading the buoy position and the base
station position during successive ten minute intervals. As con-
siderable equipment modification was being performed in conjunction
with the navigation experiments, the data are presented for only
the most frequently used station pairs (or LOPs) at the four most
used navigation markers. These are given in Table 11. These re-
sults and the others from this experiment indicate:

1) There were in the early designs two sources of error:
that associated with interfering VLF signals and a ½-lane ambig-
uity. Both sources have cures, the former by inclusion of an ap-
propriate filter and the latter by either special data processing
or by a different antenna configuration, the ambiguity being
equivalent to a polarity reversal of one of the Omega signals at
one of the reception antennas.

2) If the available data are screened for interfering sig-
nals and adjusted for the ½-lane ambiguity, an RMS error of 4
centilanes is obtained. This accuracy, which should remain stable
over 100 miles, amounts to about 800 meters.

TABLE 11. DIRECT NAVIGATION EXPERIMENTS

Buoy: N28
Distance: 0.40 nautical miles (740 m) from base station
Relative Omega coordinates in lanes (remote-base)
   AC: + .02
   BD: + .04

| Date | Time | Relative LOPs | | Remarks |
		AC	BD	
12/30/74	1400	-.01	+.58	
12/31/74	0940	-.01	+.54	
12/31/74	1219	+.51	+.17	Station C lost shortly thereafter in the midst of sampling, with the relative LOP ranges AC: -.04 to +.02 BD: +.55 to +.61
1/6/75	1344	-	+.59	

Buoy: N30
Distance: 1.21 nautical miles (2240 m) from base station
Relative Omega coordinates in lanes (remote-base)
   AC: + .03
   BD: + .15

| Date | Time | Relative LOPs | | Remarks |
		AC	BD	
12/30/74	1454	(+.70)	+.64	AC unsteady in time; strong 25 kHz interfering signal
1/6/75	1414	+.02	+.69	
1/27/75	1143	-	+.70	
3/10/75	1013	-	+.66	

Buoy: N32
Distance: 2.53 nautical miles (4700 m) from base station
Relative Omega coordinates in lanes (remote-base)
   AC: .08
   BD: .31

| Date | Time | Relative LOPs | | Remarks |
		AC	BD	
1/6/75	1445	+.14	+.85	Electrodes hanging back down- stream as much as 45° from vertical

Buoy: N32
Distance: 4.10 nautical miles (7600 m) from base station
   AC: +.17
   BD: +.50

| Date | Time | Relative LOPs | | Remarks |
		AC	BD	
1/6/75	1522	+.07	+.00	

3) The RMS error can probably be reduced somewhat by averaging the centilane (phase) information with the mini computer for longer than the estimated 30 second averaging period of the LITCOM receiver.

The same sets of experimental runs were used to make preliminary estimates of the range of which the test bed was capable, with the purpose of estimating the power and battery drain required for an actual buoy configuration. The experimental method used was to insert a radio frequency attenuator between the base station RF antenna and the BIS receiver and converter. This receiver uses a phase-locked loop in its circuitry and provides an indication of whether the loop is synchronized with an incoming signal. The experimental procedure consisted of towing the Omega test bed to a predetermined location, attenuating the signal until the receiver loop became unsynchronized, and then reducing the attenuation until the receiver resynchronized on the incoming signal. The reacquisition attenuation, in db, was plotted against distance for several experimental runs. The range extrapolated from these data with the low power ($\sim$ 125 mW) output being used is between 9 and 25 nautical miles (17-46 km). The goal of 100 miles (185 km) can be achieved with between 15 and 30 db of additional gain in the retransmission path. By simply increasing the power of the unit to 2 watts (giving 8W PEP with our modulation) 24 db are available. Alternatively, much of the needed gain can be obtained by improving the transmission antenna, the

receiver antenna, and adding a preamplifier to the BIS receiver.
An additional improvement is expected by operating at the ocean
front with maritime signal propagation conditions.

More recent experiments have used the increased data
handling capacity associated with the mini-computer becoming
available and operational. This has occurred in two phases.
The first phase allowed data to be sampled and printed out after a
selectable number of Omega receiver cycles (one cycle every 1.5
seconds). The second phase has added the capability of putting
all the incoming information on magnetic tape for further processing.

During that time service continuity statistics have been
accumulating, and diurnal shifts have been measured for various
station pairs at both the base station and at buoy N30. A summary
of these experiments is given as Table 12.

Service continuity has three states which can be discriminated
under our system. The best state is that during which the signal
quality indicator indicates a good (as opposed to poor) signal
quality. Experience shows that good quality corresponds to a
random variation of less than 10 centilanes, corresponding to
about 1 nautical mile (1.8 km). A period of poor reception can
persist in which tracking is still maintained, and this is indi-
cated by a maintenance of the lane count in our tests. Worst re-
ception causes the lane count to be lost. In an operating system,
lane count must be reacquired independently of the phase when
service is resumed. With our proposed operation, reacquisition

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TABLE 12.   OMEGA BUOY TEST SUMMARY

Run No.	Date	Total Time	Sample Interval	Position of Buoy	LOP1	LOP2	COMMENTS
1	3-21-75	65h	9m40s	Base	BC	CD	LOPs high by 8 centilanes
2	3-24-75	46h	9m40s	Marina	AC	BD	
3	3-26-75	26h42m	9m40s	Base	AC	BD	
4	3-31-75	18h30m	9m40s	N30	AC	BD	
5	4-01-75	0h32m	0m10s	Base	AC	BD	
6	4-01-75	20h6m	9m40s	Base	AC	AD	
7	4-02-75	16h40m	9m40s	N30	BD	CD	buoy lost
8a	4-03-75	3h6m		N30	BD	CD	
8	4-9-75	20h44m	3m20s	Base	BD	CD	first new format
9	4-10-75	18h38m40s	3m16s	Base	AC	BD	8 centilane problem fixed
10	4-11-75	26h19m30s	6m30s	Base	AC	BD	
11	4-14-75	37m50s	0h10s	Base	AC	BD	
12	4-15-75	16h2m	10m40s	Base	AB	AD	coding errors in plug
13	4-16-75	26h56m10s	9m40s	Base	AB	AD	
14	4-17-75	16h10m50s	9m40s	Base	BC	BD	
15	4-18-75	13h50m0s	10m0s	Base	BC	BD	

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can be done from shore stations using RDF, the entire procedure taking 1 person about half a day. The statistics gathered over several 24 hour test periods indicate that 3 stations can be received at the best quality level during 99% of each day both from the Omega system directly and via the retransmission path. A brief summary of station quality data is presented in Table 13.

The variability of an LOP obtained by monitoring a given station pair can amount to a full lane over a given month. This variability occurs over several time scales according to our observations. The most striking variability is that observed over a daily cycle, the diurnal shift. Most of this variation can be related to a predictable change in the propagation speed of the Omega signals, and so tables can be constructed to account for this part. The diurnal cycle seems to be well approximated by six straight lines, the ends of the lines corresponding to sunrise and sunset at the two Omega transmitting stations and the Omega receiver. The long-term variation, which may have a large predictable component, appears as a slight alteration in the shape of the diurnal shift curve within a single cycle or as a changing level of the daily curve over a period of several cycles. The short-term variation, for which analysis is still incomplete, appears as a jitter or uncertainty within an envelope of between two and ten centilanes total width. This variation is not completely random (uncorrelated) in appearance. It seems, in general, to be of smaller magnitude during the day than during the night.

TABLE 13.   BEST QUALITY RECEPTION EXPERIMENT SUMMARY
            (3 stations required for system operation)

DATE	DURATION OF OBSERVATIONS		SIGNAL ROUTE	% BEST QUALITY			
				A	B	C	D
3/31/75	18 h	30 m	Thru buoy at N 30	16	99.1	99.1	100
4/10/75	18 h	39 m	Base	40	99.1	99.7	100
4/11/75	26 h	20 m	Base	37	98.7	99.5	100

Our equipment makes possible a time and space correlation study of this uncertainty component, which will be required before optimum array experiments can be designed, but these studies are not in our immediate plans.

Two annotated examples of observed LOP versus time curves for a fixed object are included as Figures 37 and 38. These figures were obtained from experimental runs 3 and 4 as listed in Table 12. Ten minute samples were obtained six times per hour for 24 hours. Data in Figure 37 were obtained 26 March 1975, and data in Figure 38 were obtained 31 March 1975. The plots emphasize diurnal shifts. Figure 37 was obtained from the base station directly while Figure 38 was obtained through the retransmission path with the test buoy at marker buoy N30, 1.2. nautical miles (2.2 km) away from the base station. The separation for the BD LOP is, from the Omega tables, +15 centilanes, as shown on Table 11 of this report. The observed offset in the two curves is about +66 centilanes. This is within the range of the single point data for that buoy array in Table 11 and corresponds to 50 + 16 centilanes, taking the half-lane ambiguity into account. This twenty-four hour comparison thus reveals a 1 centilane error in the LOP between the two strongest stations.
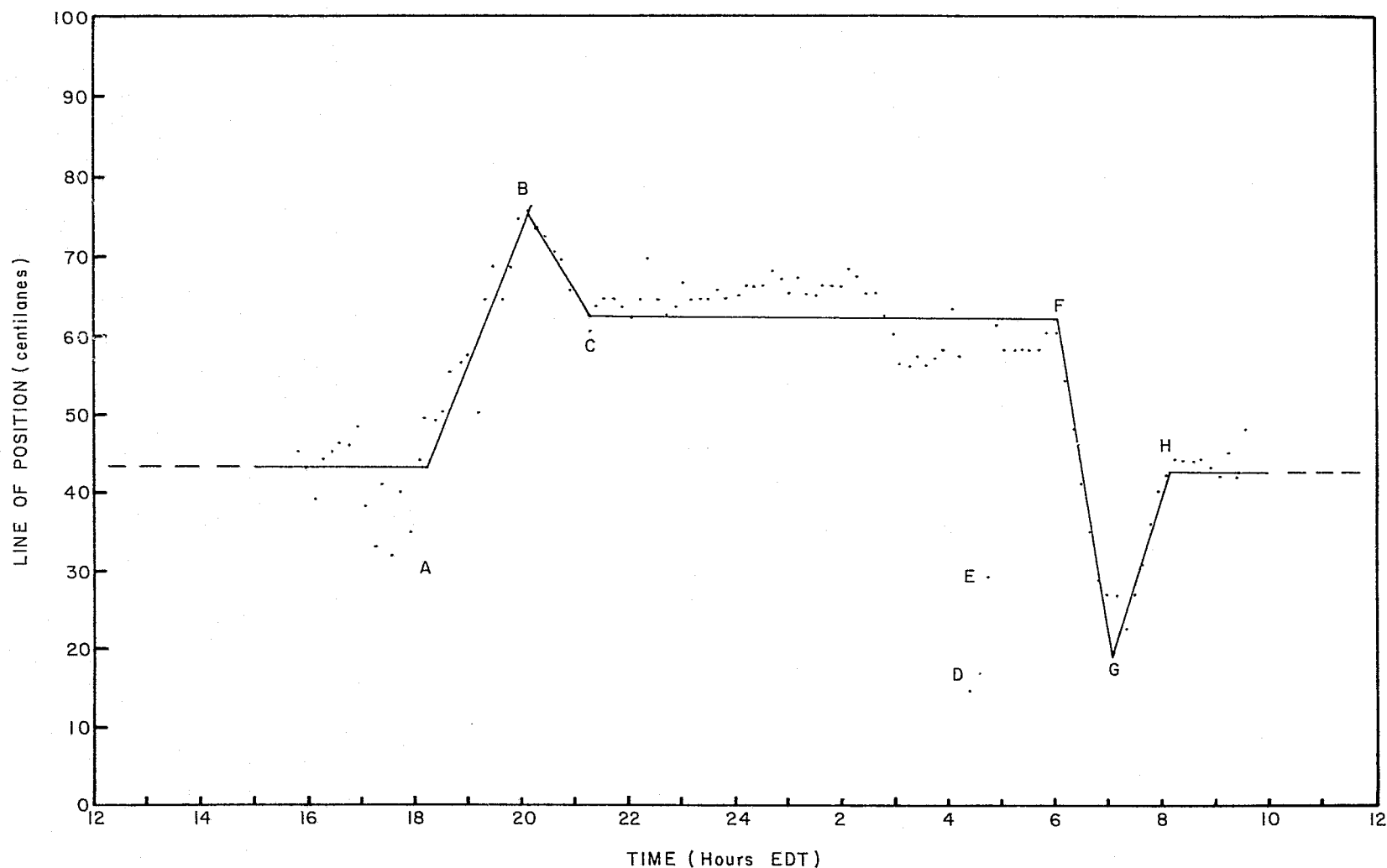
Figure 37. Diurnal cycle of Omega Line of Position (LOP) for station pair BD
(Trinidad-North Dakota) direct to base station 26 March 1975. A, B,
and C indicate sunset at Trinidad, VIMS, and North Dakota, respectively.
F, G and H are the following sunrises. E shows recovery from phase
reversal at D. An approximation to the diurnal cycle is drawn as six
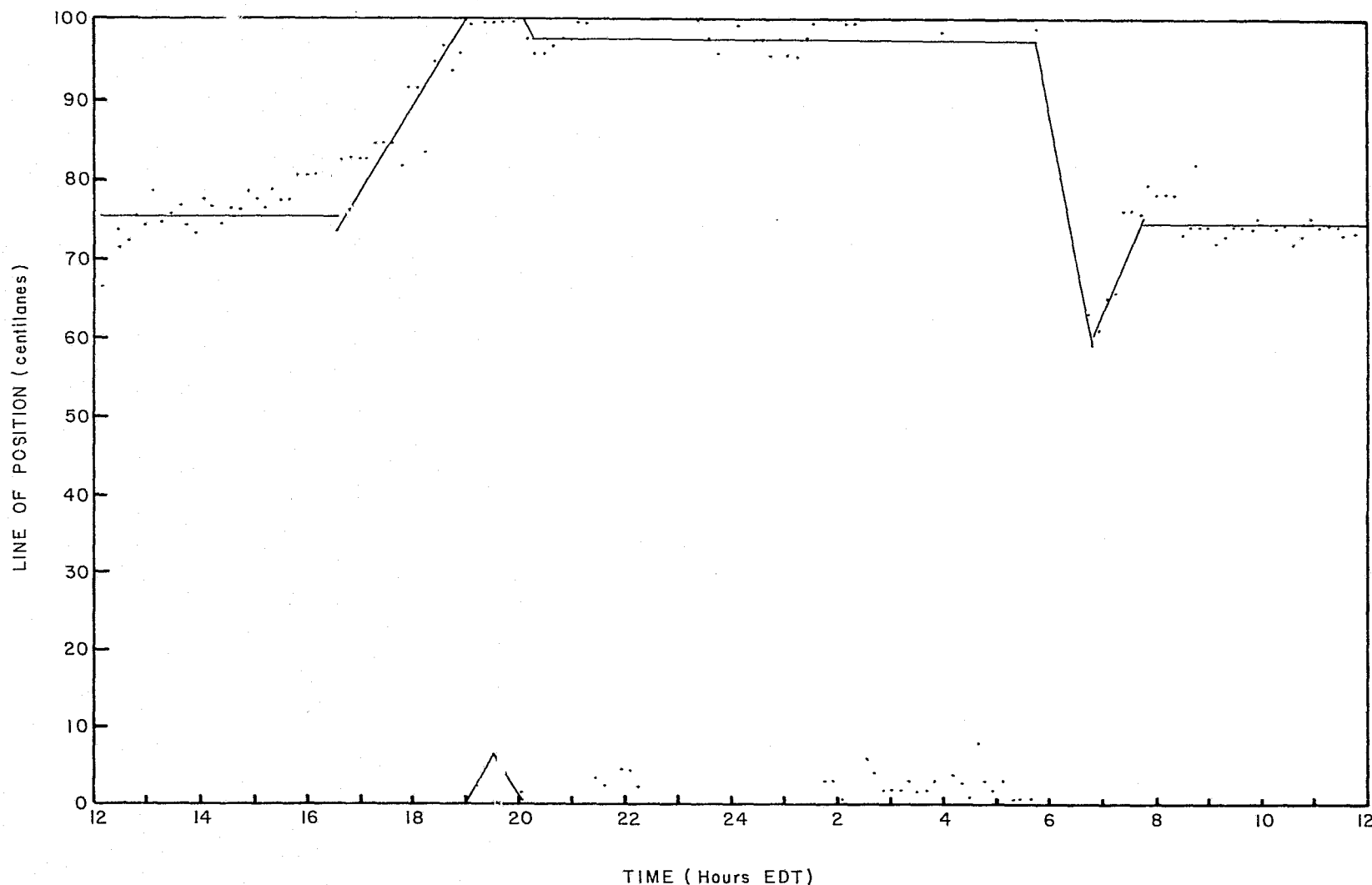straight lines. Compare with Figure 38.

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Figure 38. Diurnal cycle of Omega Line of Position (LOP) for station pair BD
(Trinidad-North Dakota) via the retransmission path with the test buoy
at marker buoy N30, 1.21 nautical miles from the base station 31 March
1975. Compare with Figure 37.

Final analysis of the existing data has not been continued under this grant. Nevertheless, the development reported here is strong support of the use of differential Omega as a method for remote tracking of objects over the continental shelf.

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A P P E N D I C E S

APPENDIX A

CORRESPONDENCE WITH USERS

DEPARTMENT OF THE NAVY

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

HEADQUARTERS

BETHESDA, MARYLAND 20084

Dr. John Zeigler
Head, Division of Physical Sciences
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

Dear Dr. Zeigler:

We have recently received help from Dr. Cristopher Welch, of the
Department of Physical Oceanography and Hydraulics, in the form of
photographs of the dye study he conducted this summer in the James River.
This work was aimed at defining the water movements, on the flood tide,
between Newport News Point and the James River Bridge.

We wish to thank him and your Division for supplying us with this data.
The information furnished by these photographs will be of great benefit
in helping us to explain certain naval material problems associated with
new naval construction at the Newport News Shipbuilding and Dry Dock Co.
yards.

Again our sincere thank you for your help.

Sincerely,

A. L. WALDRON, Head
Environment & Firefighting
Division, Code 285

C-25-00-05-5-886

May 12, 1975

Dr. C. S. Fang
Project Engineer
Department of Physical Oceanography & Hydraulics
Virginia Institute of Marine Science
Gloucester Point, Virginia   23062

Dear Dr. Fang:

We are very pleased with the remote sensing study you
conducted on the Elizabeth River concerning oil spill
information and related local circulation problems.

In our future studies, we surely will consider the
possibility of using the remote sensing technique
with aerial photography to analyze nearshore circulation
problems. We will integrate your findings into our
environmental impact study report of the newly proposed
Portsmouth Oil Refinery.

Sincerely,

Barton C. Marcy
Aquatic Technical Director

BCM/nlh

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APPENDIX B

RESEARCH PUBLICATION

APPENDIX B

RESEARCH PUBLICATION

For the first six months of the contract year, Dr. Leonard
W. Haas, Biologist, was supported by this grant. He contributed
to field efforts and supplied biological perspective to the dis-
cussions of case studies. His support was terminated when other
personnel needs assumed greater priority.

While supported by this and other grants in the past cal-
endar year, Dr. Haas, as part of his graduate work, conducted a
study of salinity structure in several nearby river estuaries.
The study has resulted in a manuscript (30 pages) which has been
submitted for publication. The title is "The Effect of the
Spring-Neap Tidal Cycle on the Vertical Salinity Structure of
the James, York and Rappahannock Rivers, Virginia, U.S.A."